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MINERALS OF ECONOMIC VALUE

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PREFATORY NOTE.

THE notes which form the subject matter of this *Bulletin* were compiled by Mr. E. S. Simpson, primarily for the purpose of meeting a much needed want on the part of the different members of the staff in dealing with the numerous inquiries on the part of the general public, in connection with what may be called Commercial Mineralogy.

A good deal of the information is scattered through various scientific and other serial publications, which are not readily accessible, and it has been felt that the publication of the data would possibly serve a much felt want in the State.

Especial reference has been made in the report to those minerals which have so far been found to occur in Western Australia, and the figures in heavy type refer to the registration number of the specimens in the collection of the Geological Survey, thus facilitating reference at any time.

The manuscript, on being submitted to the Hon. the Minister for Mines, was ordered to be printed for public information.

The index has been prepared by myself.

A. GIBB MAITLAND,
Government Geologist.

Geological Survey Office,
Perth, 9th November, 1904.

MINERALS OF ECONOMIC VALUE.

INTRODUCTION.

The notes upon which this *Bulletin* has been based were first prepared at odd intervals during the last five years in order that information might be given to officers of the Geological Staff and unofficial inquirers in regard to the less well-known minerals which have a market value either locally or in the great centres of the world's manufacturing industries.

For many years gold was almost the only mineral which attracted the attention of the lay and expert public in Western Australia, but recently more frequent inquiries have been made with regard to other sources of mineral wealth. In order to meet these, and if possible interest a larger number of prospectors and others in our latent possibilities in other directions, the original notes have been considerably enlarged and cast into a suitable form for publication.

A review of mineral statistics for the past few years shows that the five most valuable mineral products of the world are coal, clay, gold, iron ore, and petroleum. The total production of these in the whole world during 1903 may be roughly estimated by the following figures:—

Coal	£250,000,000
Clay	80,000,000
Gold	60,000,000
Iron ore	40,000,000
Petroleum	30,000,000

If the space devoted to each mineral in the following pages had been therefore dependent upon its value to mankind, an overwhelming proportion of the *Bulletin* would have been devoted to these five mineral groups. All of them are, however, of wide distribution and readily recognised, so that they have not been dealt with at any great length. Rather has it been deemed advisable to describe more fully the lesser known species, which from their rarity often command exceptional prices.

This *Bulletin* does not pretend to be a text-book of Mineralogy; it has, however, been found necessary, in order to facilitate the recognition of the various minerals, to give a short description of the appearance and character of each. In the case of precious stones this description has necessarily been in somewhat more detail than in the case of other minerals. In these descriptions the symbol "G" has been used instead of the words "Specific Gravity,"

and the symbol "H" for "Hardness" according to Mohr's scale. The following approximate terms have been used in connection with the hardness:—

Hardness	1.	Talc	... ...	Very soft
„	2.	Gypsum	... ...	„ „
„	3.	Calcite	... ...	Soft
„	4.	Fluorite	... ...	„
„	5.	Apatite	... ...	Hard
„	6.	Feldspar	... ...	„
„	7.	Quartz	... ...	„
„	8.	Topaz	... ...	Very hard
„	9.	Sapphire	... ...	„ „
„	10.	Diamond	... ...	„ „

Wherever possible reference has been made to specimens in the Museum of the Geological Survey.

The commercial value of most minerals depends upon their freedom from mechanically admixed impurities and upon their chemical composition, which even in absolutely clean, pure specimens is liable to some slight variation due to isomorphous replacement. Even traces of certain substances present from either of these causes at times have a marked effect upon the value of the bulk sample. For this reason, as far as possible, these objectionable constituents have been pointed out in the following pages. The percentages of the various constituents given are those found in the clean mineral freed from all mechanical impurity.

The many works referred to in preparing these notes cannot all be indicated, but I am especially indebted to the various volumes of the "Mineral Industry," to Dana's "System of Mineralogy," Browning's "Introduction to the Rarer Elements," Wagner and Crooke's "Manual of Chemical Technology," and Streeter's "Precious Stones and Gems."

ALUMINIUM.

Aluminium compounds are amongst the commonest constituents of the earth's crust, but it was not till 1827 that the pure metal was first prepared, whilst it is only within the last fifteen years that the cost of its production has been so cheapened as to bring it into rivalry with other more familiar metals.

The chief properties of aluminium which give it its present high importance in the arts are its lightness (its specific gravity is only 2·7 or about one-third that of iron), strength, high electric conductivity, non-poisonous character of its compounds, pleasing silver-white colour not readily tarnished or corroded, sonorousness, great affinity for oxygen, and finally the great modifications it produces in the properties of other metals when alloyed with them. It is also very malleable and ductile and a good conductor of heat.

Though compounds of aluminium are very abundant in nature, but few of them can be utilised as a source of the metal or its compounds. The most important of these are the hydrates, bauxite, gibbsite, and diaspore, and the double fluoride of sodium and

aluminium known as cryolite. Clay, felspar, and other silicates of aluminium with other metals, are seldom if ever used as a source of the metal or its definite compounds, and with the exception of clay will be dealt with under another heading (*see* page 11).

The best commercial aluminium contains 99 to 99½ per cent. of the pure metal, the balance being mainly silicon and iron. Inferior grades of metal contain 92 to 99 per cent. of the pure metal. Aluminium is largely used for cooking and other domestic utensils, for army equipments, field glasses, and other uses where lightness and durability are essentials. Its sonorousness and lightness have led to its use in sounding boards for musical instruments and large public halls. Weight for weight, aluminium is about as strong as the best steel and is much more durable, so that it is capable of replacing that metal to a large extent where expense is a secondary consideration. It has largely replaced silver for toilet, ornamental, and surgical articles, and as foil. Lithographic plates have been made of aluminium, as well as horseshoes, parts of vehicles, scientific instruments, etc. Powdered aluminium has a strong affinity for oxygen, and is therefore used for the production of flash-lights, the reduction of many metals from their ores, and the prevention of flaws in steel and iron castings.

The most important alloys of aluminium are those with copper known as aluminium-bronzes. These alloys are light and very strong and resist corrosion, with the result that they have been largely used for racing yachts, flying-machines, propellers, etc. Ferro-aluminium, an alloy of iron and aluminium, is prepared to add to steel to produce sound castings or render it more easily welded. Various alloys of aluminium with nickel, copper, zinc, etc., are used for ornamental and other purposes.

Many artificial compounds of aluminium are used in the arts, chief among them being alum; sulphate of aluminium and potassium. This is largely used in sizing paper, dyeing, manufacture of the pigments known as "lakes," hardening plaster of Paris, tanning and curing, clarifying water and other liquids, purifying sewage, etc. Aluminium sulphate is used for the same purposes as alum. Sodium aluminate is used in dyeing and printing, in hardening natural stone and making artificial stone, and in stearine candle manufacture. Aluminium acetate is used in dyeing. Ultramarine, a brilliant blue compound of aluminium, sodium, sulphur, and silica, is extensively used as a pigment and dye, and for blueing linen, paper, sugar, candles, etc.

Aluminium oxide (alumina), hydrate, chloride, and fluoride are manufactured on a large scale as intermediate products in the conversion of ores into metallic aluminium.

Corundum.—Oxide of aluminium, Al_2O_3. Aluminium, 53 per cent. The impure variety known as emery contains iron oxide, and is therefore poorer in aluminium. Crystallised, massive, or granular. Grey or tinted, translucent. (The rare transparent highly-coloured varieties are valuable gems, *see* Ruby and

Sapphire.) Very hard, brittle. G., 4·0. Found in veins or pockets in crystalline rocks, or in river gravels.

Uses.—Chiefly used as an abrasive, though to a slight extent it has been smelted into metal. For either purpose the purer the mineral the more valuable it is. Mechanically admixed impurities can be removed by mechanical concentration, but not so the iron oxide in the darker varieties known as emery. Exceptionally pure hard crystals fetch a high price for cutting and polishing diamonds and other gems.

Bauxite.—Hydrate of aluminium, with various proportions of hydrate of iron. Aluminium, 18 to 39 per cent.; alumina, 35 to 74 per cent. Massive, earthy, or concretionary. Grey, yellow, brown; opaque. Soft or hard. G., 2·5. Occurs very rarely in veins; commonly in superficial deposits produced by the weathering of crystalline rocks *in situ*, or the collection in lake beds or hollows of the products of denudation.

Uses.—This is the most important source of the metal and its compounds. Its value depends directly upon the percentage of alumina present, and upon the smallness of the iron content. Bauxite with more than 3 per cent. of iron oxide is of little value for the production of alum, etc. Most bauxites contain some silica and alumina in combination as kaolin; an ore containing any given amount of alumina and silica is of less value when these constituents are chemically combined than when they are merely mechanically intermixed. Bauxite is also used in the manufacture of very high grade and refractory crucibles and firebricks.

T. 197.—High grade Bauxite, Georgia, U.S.A.

T. 198.—Clay-like Bauxite, Co. Antrim, Ireland.

3148.—Ferruginous Bauxite, Smith's Mill. Contains alumina, 47 per cent.; iron oxide, 10 per cent.

997.—Ferruginous Bauxite, Wongan Hills. Contains alumina, 45 per cent.; iron oxide, 19 per cent.

Gibbsite.—Hydrate of aluminium, with sometimes oxide of iron. Aluminium, 32 to 34 per cent.; alumina, 60 to 65 per cent. Much so called bauxite is in reality gibbsite, or a mixture of the two. Crystallised, massive, concretionary, or stalactitic. White, grey, yellow, red; translucent or opaque. Soft, tough. G., 2·4.

Uses, etc.—Same as bauxite.

Cryolite.—Fluoride of aluminium and sodium, Na_3AlF_6. Aluminium, 13 per cent. Crystallised or massive, cleavable. Colourless, white or tinted, transparent or translucent, glassy lustre. Soft, brittle. G., 3·0. Occurs chiefly in Greenland in a vein in granite.

Uses.—A valuable ore of aluminium owing to its easy fusibility, and capacity for dissolving alumina. It is also used as a constituent of a variety of glass.

T. 196.—Cryolite, Ivigtut, Greenland.

Kaolin.—Hydrated silicate of aluminium. Aluminium, 20 per cent.; alumina, 39 per cent. Massive, compact, friable, or scaly. White, grey, or tinted. Opaque; scales, translucent. Soft. G., 2·6.

Clay is mainly kaolin admixed with more or less finely divided quartz, felspar, iron oxide, or organic matter, and occurs either in sedimentary beds or *in situ* as the result of weathering of igneous rocks.

Uses.—Clays vary largely in composition, colour, plasticity, and behaviour under heat, and according to the variations in these properties are found suitable for various purposes. An actual manufacturing test is the most satisfactory, and in some cases the only way of determining their utility. According to their purity, clays may be divided for commercial purposes into three classes, as follow:—

China Clay.—This is the purest form of kaolin used in the manufacture of porcelain and china, and to a less extent as a "filling" for paper. Finely divided quartz up to 25 per cent. does not decrease its value, but it must be sufficiently free from oxide of iron to remain white after baking, and also be sufficiently infusible to resist melting during that process. For the latter reason it must be free from any notable amount of lime or alkalies. The more plastic the clay, and the less shrinkage experienced in baking, the more valuable is it. Workable deposits of this variety of the mineral are usually in the form of irregular surface masses, resulting from the decomposition *in situ* of granite, though they are occasionally found in alluvial deposits.

Fire Clay.—The clays used for making refractory bricks, etc., are usually not as pure as china clay, but should not contain more than four per cent. of impurities other than quartz and organic matter. The best clays for this purpose are usually found in the coal measures immediately beneath the seams of coal, though they may also be found in similar situations to china clay. The best fire clays will stand intense heat without fusion or great shrinkage, will resist to a large extent the corroding action of fused mineral substances, and are not affected by sudden and great changes of temperature.

The finest grades of fire clay are employed in the manufacture of pots for melting glass, but by far the largest proportion of the total production is converted into fire brick for fire-places and furnaces, and as mortar to bind fire bricks. Large quantities are used for making crucibles for assaying and other purposes. Poorer qualities are used to make stone-ware, drain pipes, etc. The refractoriness of a fireclay depends almost entirely upon its chemical composition, more than 5 per cent. of fluxes (oxides of lime, iron, alkalies, etc.) reducing its melting point considerably. The more plastic a fire clay, the denser and stronger will be the resultant fire brick, but the greater will be the shrinkage on burning.

Brick Clay is the commonest and least pure of all useful clays. Any ordinary clay can be made into bricks, but the best are made from clays containing not less than 60 per cent. of kaolin, only a very small proportion of coarse sand, and free from pyrites and from concretions of iron oxide or carbonate of lime.

Alum Shale is a clay rock containing a considerable proportion of pyrites or marcasite, which on weathering, or roasting and leaching, yields aluminium sulphate and alum.

2563.—China Clay, North Lead, Kanowna.
2538.—Fire Clay, North Lead, Kanowna.
3152.—Fire Clay, Smith's Mill.
2736.—Brick Clay, North Lead, Kanowna.

Alunite.—Hydrous sulphate of aluminium and potassium. Alumina, 37 per cent.; potash, 11 per cent. Massive or crystallised. Soft, brittle. White, grey, or pink. Transparent to almost opaque. G., 2·6.

Occurs as irregular pipes or veins in trachytic or granitic rocks.

Uses.—A common source of alum and aluminium sulphate.

ANTIMONY.

Antimony has been known from time immemorial, an ancient Chaldean vase having been discovered made of this metal. It is a brilliant silver-white metal, coarsely crystalline in structure when melted and cooled slowly, but granular when quickly cooled. It is hard and very brittle, not affected by the air at ordinary temperatures, but, on heating, burns with the production of the oxide. It is attacked by most mineral acids.

The metal occurs native in several parts of the world, usually in veins in crystalline rocks. It is not, however, an important ore. The most common ore is the sulphide, stibnite, which, at the surface, is found altered to one or other of the oxides, cervantite, etc. An oxysulphide, kermesite, has been mined in Italy. Antimony ores occur in veins of quartz or calcite in slates, granites, and other crystalline rocks.

Though known for so long, the use of antimony in the arts has never been very extended; even now, practically, its only use is in the form of alloys with other metals, which are thereby rendered harder and more lustrous. The most important of all antimony alloys are those with lead. Type metal is an alloy of lead, tin, and antimony. The hard lead used for coffins, and for pumps and pipes, and acid chamber linings in chemical factories, contains several per cent. of antimony. Britannia metal, pewter, and many anti-friction metals contain a considerable percentage of this metal. Much of the antimony used for the preparation of these alloys comes into the market in the form of antimonial or hard lead, a by-product of lead smelters. It contains 18·27 per cent. of antimony.

Of artificial compounds, the most important is the tri-sulphide, which is one of the chief constituents of the heads of safety matches, and is also used in pyrotechny and medicine. The penta-sulphide is used to vulcanise caoutchouc. Potassium antimonate, or tartar emetic, is used in medicine and as a constituent of certain varieties of glass. Neapolitan yellow, lead antimonate, is used as a pigment, and as a constituent of stained glass. Antimony-cinnabar (an oxy-sulphide) is used as a pigment.

Stibnite.—Trisulphide of antimony, Sb_2S_3. Antimony, 71 per cent. Coarsely or finely crystallised, massive or granular. Lead coloured and brilliant or iridescent; opaque. Very soft and easily fusible. G., 4·6.

Uses.—This is the chief ore of antimony and most important source of the metal and its compounds. For export, it should be dressed by hand or otherwise up to at least 50 per cent. By heating it may be melted and run off from the gangue and cast into ingots for export. The value of the concentrates will depend not only on their contents in the metal but also on their freedom from compounds of arsenic and lead, and in many cases upon the proportion of gold and silver present.

5028.—Massive Stibnite, Mallina.
3706.—Crystallised Stibnite, Mt. Magnet.
1374.—Crystallised Stibnite, Metz, N.S.W.

Kermesite.—Oxysulphide of antimony, Sb_2S_2O. Antimony, 75 per cent. Usually crystallised. Red, opaque, brilliant lustre. Very soft, sectile. G., 4·5.

Uses.—Sometimes occurs in sufficient quantity to form a source of the metal.

Valentinite.—Trioxide of antimony, Sb_2O_3. Antimony, 83 per cent. Crystallised or massive, granular. Brilliant lustre; white, pink, or grey; translucent. Soft. G., 5·6.

Uses.—Used as a source of the metal and its compounds.

1364.—Crystallised Valentinite, Hillgrove, N.S.W.
T. 10.—Massive Valentinite, Borneo.

Cervantite.—Tetroxide of antimony, Sb_2O_4. Antimony, 79 per cent. Crystallised or massive. Yellow, opaque. Soft, brittle. G., 4·0.

Uses.—Used as a source of the metal and its compounds.

1921.—Massive Cervantite, Wiluna.
5195.—Cervantite crust on Stibnite, Mallina.

ARSENIC.

Arsenic in its properties lies on the borderland between the metals and the non-metals. It was known to the Ancient Greeks. It is a steel-grey crystalline solid of metallic appearance, brittle, and a good conductor of electricity. It tarnishes rapidly in moist

air, and when heated volatilises without melting. It is somewhat lighter than antimony.

Arsenic occurs occasionally uncombined in nature, but its commonest ore is mispickel, a sulpharsenide of iron. Sulphides of arsenic occur native, as also arsenides of iron nickel and cobalt. Arsenic and its compounds usually occur in veins in crystalline rocks.

The element has no use in the arts except to add to lead for making shot.

Of its artificial compounds the most important is the trioxide, known as white arsenic. Owing to its extremely poisonous character large quantities of white arsenic are used to destroy vermin and insect pests, and also as a preservative of timber, skins, leather, etc. It is also used to prevent and cure foot-rot in sheep. Large quantities are used to produce several green pigments (notably Paris green), which are compounds of this oxide with oxide of copper, etc. It also enters into the composition of some varieties of glass. Several compounds of arsenic are used in medicine.

Mispickel (Arsenical Pyrites, Arsenopyrite).—Sulpharsenide of iron, $FeAsS$. Arsenic, 46 per cent. Crystallised or massive. Light grey, metallic, brilliant, opaque. Brittle, hard. G., 6·0.

Uses.—Used as a source of white arsenic, etc. Some samples contain a notable proportion of gold or cobalt, which will pay for extraction, when white arsenic may be collected as a by-product during the necessary roasting.

1112.—Mispickel, Coolgardie.
T. 142.—Mispickel, Nova Scotia.

BARIUM.

This metal, which resembles calcium but is much more uncommon, was first separated early in the 19th century, though some of its compounds were known as far back as the 17th century. It is silver white, soft, and readily oxidises in the air. At ordinary temperatures it decomposes water with the evolution of hydrogen. At a dull red heat it melts.

Barium does not occur native. Its most important ore is the sulphate, barytes, which occurs either in veins in crystalline or other rocks or as boulders in residual clays resulting from the weathering of limestone. A less common though valuable ore is the carbonate, witherite, workable deposits of which occur as veins in limestone, etc.

Neither metallic barium nor alloys of it with other metals have any application in the arts. Pure artificial barium sulphate or blanc fixe is used for the same purposes as the mineral sulphate, *q.v.* It forms the chief constituent of "lithophone," a white paint which has largely replaced white lead for many purposes. The hydrate is extensively used to extract sugar from molasses, as

well as to make white paints and to soften boiler waters. Barium peroxide is used to prepare hydrogen peroxide and oxygenated water for bleaching, etc. The chloride is used in making paint as also the sulphide. This latter compound is also used to remove hair from hides, etc. The carbonate is used in manufacturing cyanides and fire bricks.

Barytes.—Sulphate of barium, $BaSO_4$. Baryta (barium oxide), 65 per cent. Crystallised, laminated, or granular massive. White or tinted, transparent to opaque. Brittle, soft. G., 4·5.

Uses.—After cleaning and grinding is added to white lead and zinc white. It is used in weighting and filling paper, making enamels and porcelain, in pyrotechny, and as a source of various barium compounds. The value of barytes depends upon its freedom from mechanically and chemically contained impurities, especially from iron compounds and other colouring materials.

204.—Massive Barytes, Northampton.
4451.—Crystallised Barytes, Oakover River.

Witherite.—Carbonate of barium, $BaCO_3$. Baryta, 77 per cent. Crystallised, massive, or globular. White, grey, or yellow, translucent. Soft, brittle. G., 4·3.

Uses.—An important source of all barium compounds, especially the peroxide.

BISMUTH.

This metal has been known to chemists for some centuries, though it is comparatively rare. It is a hard brittle metal of a dark reddish grey colour, and coarsely crystalline in structure when slowly cooled after fusion. It oxidises slowly in air at ordinary temperatures, more rapidly on heating. It dissolves readily in most mineral acids. Its specific gravity is between those of copper and silver.

Bismuth occurs in nature as the almost pure metal as well as the sulphide, bismuthinite, and the carbonate, bismutite. These are the only important ores, though bismuth also occurs as the oxide and telluride, and in several complex sulphides of lead and copper. Bismuth ores are found in veins of quartz or calcite, in slates, or crystalline rocks.

The market for bismuth ores is strictly limited, and is controlled by Messrs. Johnson, Matthey & Co., of London, and the Government of Saxony.

The metal bismuth is only employed in the form of alloys, many of which are of considerable value. Fusible metal is an alloy of bismuth, lead, and tin, and sometimes cadmium, which melts at a very low temperature, which can be varied by varying the relative proportions of the constituents. Owing to its expansion on solidification it gives a very perfect cast, and for this reason is used for stereotyping, making casts of woodcuts, etc. On account of its low and adjustable melting point it is used for safety plugs

for boilers, for automatic fire extinguishers, for baths, for tempering steel, and for solders. The pencils for writing on so called metallic paper are made of a bismuth alloy.

Bismuth oxide is used as a constituent of optical glass and of various glazes for porcelain and stained glass. Basic bismuth nitrate is largely used in medicine and also as a cosmetic. Several other bismuth compounds are used in medicine.

Bismuth (Native).—Pure bismuth, 94 to 99 per cent. Opaque metallic, reddish white to reddish grey. Foliated, massive or granular. Brittle, sectile. Very soft. G., 9·8.

Uses.—This is the chief source of bismuth and its compounds. Ore as low in grade as 5 per cent. is saleable, but it is more economical to handpick or otherwise dress the ore up to at least 25 per cent. before exporting. Gold and sometimes silver are constituents of native bismuth, and contribute largely to the value of the ore. The presence of tellurium in bismuth ore is a decided drawback, as it injures the qualities of the smelted metal.

2292.—Auriferous Bismuth in Quartz, Yalgoo. Ore assays bismuth, 2·6 per cent.; gold, 70·0 ozs. per ton; silver, 3·0 ozs. per ton.

Bismuthinite.—Sulphide of bismuth, Bi_2S_3. Bismuth, 81 per cent. Sometimes crystallised, usually foliated or fibrous massive. Metallic, opaque, lead grey. Very soft. G., 6·4.

Uses.—A less common ore of bismuth. (*See* remarks under Native Bismuth.)

T. 14.—Bismuthinite, Cornwall, England.

Bismutite.—Hydrated carbonate of bismuth. Bismuth, 80 per cent. Opaque, earthy, or in crusts. White, yellow, or greenish. Soft. G., 7·0.

Uses.—*See* remarks under Bismuthinite.

BORON.

This non-metallic element was first separated in the elemental state in 1808, but its most important compound, borax, has been known for several centuries. Boron is a light brown powder, very infusible, and a strong reducing agent.

Boron does not occur native. The most widely-distributed compound of it is tourmaline, a complex silicate of boron, aluminium, etc., frequently occurring as a constituent of granite. This mineral is, however, not a source of the commercial compounds of boron. These are derived from deposits of sassolite (boracic acid), borax (sodium borate), colemanite (calcium borate), and boracite (magnesium chloro-borate). Sassolite is obtained from hot springs; the other boron minerals are found in recent beds, usually in marshes or dry lakes in desert regions and in the neighbourhood of tourmaline-granites.

By far the most important compound of boron is borax, the uses of which are described under the native mineral. Boracic acid is also of considerable use as described under sassolite. The uncombined element has no application in the arts.

Sassolite.—Boracic acid, H_3BO_3. Boron trioxide 56 per cent. Scaly or stalactitic. White, transparent, or translucent. Very soft. G., 1·5. Occurs solid in volcanic regions, or dissolved in the waters of hot springs.

Uses.—The crude mineral is purified by crystallisation, and is then used as an antiseptic and food preservative as well as for sundry medicinal purposes.

Borax (Native).—Hydrous borate of sodium; boron trioxide, 37 per cent. Crystalline, white, brittle. Translucent to opaque. Soft. G., 1·7. Occurs as a crystalline efflorescence on the surface of dry lakes and in crystals embedded in the mud beneath them. Also in solution in waters of arid regions.

Uses.—The crude mineral is purified by recrystallisation and is then used as a food preservative and antiseptic, as a flux in many metallurgical operations; as a constituent of glass, artificial gems, enamels, and pottery-glazes, as a flux in welding and soldering, for softening water, and for various medicinal purposes.

Colemanite.—Hydrous borate of calcium. Boron trioxide, 51 per cent. Crystallised or massive. White, brilliant lustre, transparent to translucent. Hard. G., 2·4. Occurs in recent or ancient lake beds similarly to borax.

Uses.—An important source of boracic acid and borax. Value depends upon percentage of boron trioxide.

Boracite.—Chloro-borate of magnesium. Boron trioxide, 62 per cent. Crystallised or granular massive. White, translucent. Hard. G., 2·9. Occurs interbedded with salt and gypsum in ancient lake beds.

Uses.—A source of boracic acid and borax. Value depends upon percentage of boron trioxide.

CADMIUM.

This rare metal, discovered early in the 19th century, closely resembles zinc in appearance and properties, and is usually associated in nature with that metal. It is bluish white in colour, malleable and ductile. It tarnishes readily in the air, and at a high temperature burns. Its weight is the same as that of copper.

Cadmium does not occur native, but is known as a sulphide, greenockite. The chief sources of the metal are, however, cadmiferous varieties of the zinc ores blende and smithsonite, cadmium being obtained as a by-product in the smelting of such ores for zinc.

Metallic cadmium is used to a slight extent in analytical chemistry and as a constituent of certain fusible metals. An alloy

of silver and cadmium is used for plating purposes, for which it is found very advantageous. It has also been proposed to use the metal as a coating for battery terminals and connections. Cadmium sulphide is used as a pigment and in pyrotechny, and the iodide in photography.

Greenockite.—Sulphide of cadmium, CdS. Cadmium, 77 per cent. Crystallised, yellow, brilliant lustre, translucent. Brittle, soft. G., 5·0.

Uses.—A minor source of cadmium and its compounds.

Cadmiferous Blende.—Sulphide of zinc and cadmium (ZnCd)S. Cadmium up to 5 per cent. Resembles ordinary blende. *See* page 61.

Uses.—Chief source of cadmium, obtained as a bye-product in smelting for zinc.

4032.—Cadmiferous Blende, Northampton.

Cadmiferous Smithsonite.—Carbonate of zinc and cadmium, $(ZnCd)CO_3$. Cadmium, up to 3 per cent. Resembles ordinary smithsonite, *q.v.* page 61.

Uses.—A source of cadmium and its compounds.

CALCIUM.

Though compounds of calcium are amongst the commonest minerals on the earth's surface, and their properties have in many cases been known for centuries, the metal itself was only obtained in a state which permitted of handling and examination in 1856. It is a soft yellowish metal, somewhat stable in perfectly dry air, but readily converted into the oxide (lime) in moist air, and acted on by water with violence. It is one of the lightest metals known, being much lighter than aluminium.

Calcium does not occur in nature in the metallic state. Its commonest compound is the carbonate, calcite, which forms the chief constituent of all limestones, as well as of the shells of mollusca. In combination with silica, calcium forms a large proportion of many igneous rocks; the hydrated sulphate, gypsum, is of common occurrence. Phosphate of calcium forms the chief constituent of the bones of men and animals, as well as occurring as rock phosphate and in guano.

The metal itself has not as yet been put to any useful purposes. Its most useful artificial compound is the oxide, known as lime, formed by burning calcite in the form of limestone. Portland cement is a mixed silicate and aluminate of calcium formed by burning a natural or artificial mixture of calcite and clay. A very pure limestone on burning yields a fat or pure lime, one with a little clay yields a hydraulic lime, capable of setting under water, one with still more clay yields a hydraulic (or Portland) cement. Though the chief use of lime is for building, large quantities of it are also employed for other purposes, such as the preparation of bleaching powder (chloride of lime), ammonia, caustic soda, and

caustic potash, for purifying water, in cyanide works for neutralising acid, and for various other metallurgical purposes, as well as a fertiliser.

Sulphate of lime, produced by burning gypsum, is known as Plaster of Paris, and is employed either solely or with various added chemicals for finishing off the interior walls of buildings, as well as for making various mouldings and castings. "Superphosphate," a material largely used as a fertiliser, is a mixture of calcium sulphate and acid calcium phosphate, formed by acting on natural lime phosphates with sulphuric acid.

Chloride of lime or bleaching powder, used extensively for disinfecting and for bleaching, is a compound formed by allowing fat lime to absorb chlorine gas. Calcium carbide, now used to generate acetylene gas for lighting purposes, is a compound obtained by smelting together charcoal, or coke, and lime in an electric furnace.

Calcite.—Carbonate of calcium, $CaCO_3$. Lime, 56 per cent.; carbon dioxide, 44 per cent. Crystallised or massive, white, or tinted various colours, transparent or opaque. G., 2·7. Calcite forms rock masses under the names of *limestone* and *marble*.

Uses.—Chiefly used for burning into lime. To make the best lime for mortar or for use in preparing other calcium compounds or for other chemical purposes, the limestone should be practically free from silica, alumina, iron, and magnesia. For making Portland cement limestone should be free from iron, magnesia, and sulphur, but may with advantage contain silica and alumina equivalent to anything up to 25 per cent. of clay. A limestone containing in itself sufficient clay to form a Portland cement is known as a "*natural cement-rock.*"

Immense quantities of limestone are used for building purposes, for which the chief requisites are strength, freedom from pores, and capacity for resisting the weather.

Large quantities of limestone are used as a flux in smelting ore of iron, lead, copper, etc. For this purpose it is necessary that the stone should be rich in lime and low in silica (not more than 5 per cent.) and sulphur. Small proportions of iron and magnesia do not affect its value for this purpose.

The second constituent of calcite, viz., carbon dioxide or carbonic acid gas, is obtained from it by the action of suphuric acid, and is largely used in aerated water factories, etc. Any pure limestone is suitable for this purpose.

Perfectly transparent flawless crystals of calcite (Iceland Spar) are of considerable value for optical purposes.

2066.—Calcite Crystals, Coolgardie.

1015.—Crystalline Massive Calcite, Broad Arrow.

4471–73.—Stalactitic and stalagmitic Calcite, Blackboy Hollow Cave, Sussex District.

5371.—Calcite (Travertine), Leonora.

4431.—Limestone, Rottnest Island.

Dolomite.—Carbonate of calcium and magnesium (CaMg) CO_3. Lime, 30 per cent; carbon dioxide, 47 per cent. Similar to calcite, but slightly heavier. Forms rock-masses under the name of *magnesian limestone* or *dolomite*.

Uses.—With a natural or artificial admixture of clay, is burnt to form Rosendale hydraulic cement, for which purpose it should be low in iron and sulphur. Used in case of ordinary limestone as a flux, when the silica present should not exceed 5 per cent. Also used as a source of carbonic acid, for which purpose it is, if anything, more valuable than ordinary limestone. Large quantities are used as building stone. Sometimes used as a source of magnesia.

1988.—Crystallised Dolomite, Goongarrie.

5342.—Crystalline massive Dolomite, Porlelle.

Gypsum.— Hydrated sulphate of calcium, $CaSO_4 2H_2O$. Lime 32 per cent. Colourless, white or tinted; transparent to opaque; very soft. In large crystals, or crystalline masses, or as a fine crystalline powder. G., 2·3. Workable deposits occur in the beds of dry lakes or in sedimentary beds.

Uses.—Chiefly used in the manufacture of Plaster of Paris and various patent plasters. For this purpose it must be very pure and especially free from iron oxide, which would give the plaster an objectionable tint. It is used occasionally as a fertiliser, especially for grape vines. The massive variety, *alabaster*, is extensively carved into ornamental vases, etc.

5055.—Powdery Gypsum, near Cliffy Head, Victoria District.

1504.—Clear Crystallised Gypsum, Mingenew.

2360.—Fibrous Gypsum, Boulder.

Apatite.—Phosphate and chloride or fluoride of calcium, $3Ca_3P_2O_8Ca\,(FCl)_2$. Lime, 54 per cent.; phosphorus pentoxide, 41 per cent. Massive or crystallised; white or tinted; transparent to opaque; brittle, hard. G., 3·2. Payable deposits occur in veins and bunches in pyroxenite and other crystalline rocks.

Phosphorite or *Rock-phosphate* is an impure apatite occurring in irregular beds or nodules in limestone.

Guano, the earthy or hardened excreta of sea-birds, consists largely of macerated bones of fish, and therefore of impure calcium phosphate.

Uses.—The main use of apatite and similar compounds is as a fertiliser, either in the crude state or after conversion into "superphosphate." They are also used as a source of phosphorus, largely employed in the match industry, etc., and in the manufacture of white opaque glass. For these purposes the value of the ore depends upon the percentage of phosphorus pentoxide present. In addition to calcium phosphate, guano also contains ammonia and other nitrogen compounds, which add to its value as a fertiliser. Its value, therefore, depends primarily on the percentage of phosphorus pentoxide, next upon the percentage of nitrogen present. For use in the manufacture of superphosphate over 3 per cent. of oxides of

iron and alumina is looked upon as a serious drawback in any sample of rock phosphate or apatite; while the presence of a few per cent. of carbonate of lime is an advantage. For export, rock phosphate should contain not less than 65 per cent. of calcium phosphate; for local consumption, not less than 55 per cent.

5189.—Rock Phosphate, Clinton, S.A.

Fluorite (Fluorspar).—Fluoride of calcium, CaF_2. Calcium 51 per cent.; fluorine, 49 per cent. Crystallised, massive or granular. Transparent to translucent. Colourless or tinted various colours. Soft, brittle. G., 3·2. Occurs usually in veins in limestones and various crystalline rocks.

Uses.—Fluorspar is mainly used as a flux, in the open-hearth method of producing steel, and in remelting pig iron in foundries. It is frequently used to add to smelting mixtures not otherwise readily fusible, whilst it is said to assist materially in purifying crude copper. Smaller quantities are used in the production of opalescent glass and enamelled ware and of hydrofluoric acid. Fluorspar is occasionally cut into gems and ornaments. For use in steel production it should be free from sulphur and phosphorus, whilst for all purposes more than 1 per cent. of silica is a decided disadvantage.

CARBON.

Carbon is one of the commonest of the non-metallic elements, and numbers amongst its natural and artificial compounds many of the most useful substances known to civilisation.

It is known in three different modifications, diamond, graphite, and charcoal. Diamond is crystalline, colourless, transparent, and of high refractive index. It is harder than any other known substance, but somewhat brittle. Its specific gravity is 3·5. Graphite is crystalline, grey-black, opaque, with metallic lustre. It is very soft and smooth to the touch. Its specific gravity is 2·3. Charcoal in its purest form is a black amorphous powder, dull and opaque. It is variable in hardness and specific gravity, according to the method by which it has been formed.

Both of the crystalline forms of carbon, diamond, and graphite occur as minerals, but not so the amorphous form, unless possibly as a constituent of coals. The most important mineral compounds containing carbon are coal, petroleum, natural gas, and diamond, the first three of which owe their chief value to the ease with which they burn with the evolution of light, or heat, or both.

Diamond.—The purest forms of this mineral are dealt with under the heading "Gems," p. 67.

Bort and Carbonado.—Almost pure carbon of the diamond type. Grey or black, translucent to opaque. No distinct crystalline outline, usually in irregular water-worn grains. Extremely hard. G., 3·3. Occurs in river gravels.

Uses.—The chief use of these minerals is for setting in the crowns of rock-drills and the edges of lapidaries cutting wheels, and for polishing diamonds or other gems.

Graphite.—Almost pure carbon of the graphitic type. Sometimes in tabular crystals, more often in scales, or in scaly, columnar, or earthy masses. Black or dark grey, lustre usually metallic, sometimes dull; opaque. Very soft. G., 2·2. Occurs in beds or bands in metamorphic rocks, either gneiss, mica schist, quartzite, or crystalline limestone.

Uses.—The greater part of the world's production of graphite is used for mixing with fireclay to make crucibles for melting metals and alloys in. Smaller quantities are used for stove polish, foundry facings, paint, lubricating, lead pencils, and various electrical purposes. The purest forms of graphite are used for crucibles and lubricating. For these purposes the graphite should contain 95 per cent. of pure carbon, whilst for crucibles the ash should be infusible, and for lubricating, the mineral very flaky and greasy. Less pure varieties of the mineral can be used for the other purposes named, and command a correspondingly lesser price. Natural graphite has recently to a large extent been replaced by artificial graphite made from coke in the electric furnace.

3438.—Graphite. Oldfield River.

T. 17.—High-grade Graphite, Ceylon.

Coal.—This is a mixture of various compounds of carbon, hydrogen, oxygen, nitrogen, and sulphur, derived from the gradual alteration of buried vegetable matter. Five main types exist, viz., brown coal, non-caking bituminous, caking bituminous, anthracite, and algal coal.

Brown Coal.—Contains moisture 15 to 50 per cent.; ash, 1 to 35 per cent. Balance of coal contains carbon 55 to 71, hydrogen, 4 to 6, oxygen and nitrogen, 21 to 37. Ratio of fixed carbon to volatile hydrocarbons, 1 : 2 to 2 : 1. Brown and dull to black and bright. Sometimes with woody structure and then known as *Lignite*; when very bright and black, known as *Jet*.

Uses.—This is the poorest class of coal, and owing to the high percentage of moisture in it, it has to be sun-dried or artificially dried before use. The drying is frequently followed by compressing into briquettes. This coal is mainly used for household purposes, though it can also be used for steam-raising. The less ash and moisture in it the higher its calorific value, and therefore the more valuable it is.

623.—Brown Coal, Coolgardie.

2996.—Brown Coal, Fitzgerald River.

Non-caking Bituminous Coal.—Contains moisture, 5 to 15 per cent.; ash, 1 to 30 per cent. Balance of coal contains carbon, 70 to 85; hydrogen, 4 to 6; oxygen and nitrogen, 12 to 20. Ratio of fixed carbon to volatile hydrocarbons, 1 : 1 to 2 : 1. Bright or dull, black.

Uses.—A more useful type of coal than lignite, and can be used for all ordinary purposes such as steam-raising, gas-making, household use, tar-making, smelting, etc. It cannot be used for making coke, and is of small value for marine or locomotive engines.

5054.—Non-caking Bituminous Coal, Collie.

1994.—Non-caking Bituminous Coal, Collie.

Caking Bituminous Coal.—Contains moisture, 1 to 5 per cent.; ash, 1 to 30 per cent. Balance of coal contains carbon, 75 to 90 per cent.; hydrogen, 4 to 6; oxygen and nitrogen, 5 to 11. Ratio of fixed carbon to volatile hydrocarbons, 2 : 1 to 6 : 1. Bright or dull, black.

Uses.—The most useful of all kinds of coal. Suitable for household use, steam-raising under all conditions, coke-making, and gas, with accompanying production of ammonia, tar, cyanides, and numberless organic compounds. For steam raising its value depends upon the amount of heat generated in burning, freedom from ash, and infusibility of ash. For coking, its value depends upon quantity and hardness of coke and freedom from ash. For gas making, upon quantity and quality of gas given off on coking.

725.—Caking Bituminous Coal, Newcastle, N.S.W.

Anthracite.—Contains moisture ·5 to 2 per cent.; ash, 1 to 30 per cent. Balance of coal contains carbon, 90 to 96 per cent.; hydrogen, 2·5 to 5 per cent.; oxygen and nitrogen, 2 to 6 per cent. Ratio of fixed carbon to volatile hydrocarbons 6 : 1 to 10 : 1. Black, bright, hard. Not easily combustible, and does not form coke.

Uses.—This is the best coal for marine and locomotive purposes. Navies use it almost exclusively owing to its smokeless character and its high calorific value. It is also largely used for smelting and other purposes, but is useless for gas making. Its value depends upon the amount of heat generated in burning, freedom from ash, and infusibility of ash.

Algal Coal.—This includes *Kerosene Shale*, *Boghead Coal*, and *Torbanite*, all of which are largely composed of the *débris* of water plants. They contain moisture, 0·1 to 2 per cent.; ash, 1 to 40 per cent., graduating into an oil-shale as the ash increases. Balance of coal contains carbon, 78 to 80 per cent.; hydrogen, 12 to 14 per cent.; oxygen and nitrogen, 6 to 8 per cent. Ratio of fixed carbon to volatile hydrocarbons, 1 to 2 to 1 to 15. Dark brown; dull; tough; elastic. Catches fire readily and burns without melting.

Uses.—This coal is chiefly used to mix with bituminous coals for the production of illuminating gas. It is also distilled to yield oils (both illuminating and lubricating), paraffin wax, and ammonia. Its value depends upon the quantity and quality of its volatile products.

3123.—Kerosene Shale, Joadja, N.S.W.

Petroleum.—A natural liquid oil varying considerably in composition, but consisting mainly of a mixture of hydrocarbons of

the paraffin and naphthene series, the carbon varying from 79 to 87 per cent. Transparent to translucent; colourless, yellow, brown, or black. G., 0·7 to 1·0. Occurs in sedimentary deposits, in porous beds or cavities sealed by impervious beds of clay, etc., especially beneath anticlinal folds.

Uses.—Used extensively for steamers, locomotives, etc., in the crude state as fuel. Also distilled in large amounts, producing illuminating gas, light oils (gasolene, etc.), used for motors, etc.; illuminating oils (kerosene, etc.); heavy lubricating oils; vaseline or petroleum jelly, used as fuel, lubricant, etc.; paraffin wax, and sometimes asphalt or pitch. The most valuable petroleum is that which yields most illuminating oil, has the highest calorific value, and contains least sulphur. In America crude petroleum is used for watering the streets to keep down the dust, and is found far superior to water.

Natural Gas.—This contains from 93 to 97 per cent. of marsh gas or methane, the balance being nitrogen. It is the most perfect and convenient fuel known, 11 cubic feet giving approximately the same amount of heat on burning as a pound of good steam coal. It occurs in pores and cavities in sedimentary rocks of all ages, usually in association with petroleum.

Uses.—Largely used as a fuel for domestic and manufacturing purposes, its freedom from soot and ashes being a great advantage. It is used for melting steel, reheating iron, burning brick, steam-raising, etc.

Asphaltum.—A mixture of various hyhrocarbons partly oxygenated and invariably carrying sulphur. Analyses usually show the presence of ash, non-bituminous organic matter, petrolene, and asphaltene, all in varying quantities. Amphorous, solid, or semi fluid. Black or dark brown, opaque. Melts and burns readily. G., 1 to 1·8. Occurs in surface beds or disseminated through sandstones or limestones. Usually closely associated with petroleum.

Uses.—The chief use of asphalt is as a binding material for crushed rock, etc., for roadways, footpaths, and foundations, damp courses in houses; as a protective covering for wood or iron; as an ingredient of roofing felt; as an ingredient of various varnishes and japans. For street paving the asphalt may be already naturally mixed with the necessary quantity of rock. Otherwise the less ash the better, whilst the proportion of non-bituminous organic matter should not exceed 15 per cent. of the total organic matter, and the proportion of petrolene should exceed that of asphaltene. The purest varieties only of asphalt can be used for making varnishes. These should be hard, have a very bright lustre and pure black colour, and be practically free from ash and non-bituminous organic matter.

3429.—Drift Asphaltum, Warren River, Nelson District
4448.—Drift Asphaltum, Doubtful Island Bay, Kent District.

Ozokerite.—Mixture of solid hydrocarbons of the paraffin series. Amorphous, wax-like. White, yellow, or brown; translucent. G., 0·9. Occurs in veins or irregular deposits in sedimentary beds in association with asphaltum and petroleum.

Uses.—Chiefly used as a source of mineral wax or cerasin, the applications of which are numerous, such as making candles, waxed paper, adulterating beeswax, etc. For this purpose its value depends upon the percentage yield of purified white wax. Also used as a source of illuminating gas, oils, etc.

CERIUM.

This rare metal was discovered in 1803. It is a soft, grey, ductile metal, which burns readily in airlike magnesium. It is a little lighter in weight than iron, and like that metal is not readily affected by dry air, but is susceptible to moist air. The metal itself has no application in the arts.

Cerium does not occur free in nature, but, together with several other similar rare metals, occurs as a constituent of certain silicates and phosphates occurring sporadically in crystalline rocks, especially granite and gneiss, and in the heavier sands derived from their degradation. It is the latter which form the chief sources of the metal.

The most important compound of cerium is the dioxide which forms a small proportion of the Welsbach incandescent mantle and the glower of the Nernst lamp, this oxide having the property, possessed in a still higher degree by the oxide of thorium, of glowing with an intense light when heated. Cerium nitrate is prepared largely for use in the manufacture of the Welsbach mantles. Both this salt and cerium oxalate are used to a slight extent in medicine.

Monazite.—Phosphate of cerium, lanthanum, and didymium $(CeLaDi)PO_4$. Cerium oxide, 16 = 37 per cent. This is the commonest cerium mineral, but as its value depends almost entirely upon the small and variable proportion of thorium oxide contained in it, it will be treated fully under Thorium, page 52.

5437.—Monazite Sand, North Carolina, U.S.A.

Cerite.—Hydrous silicate of cerium, lanthanum, didymium, iron and lime. Cerium oxide, 25 = 65 per cent. Brown or grey; opaque; as hard as felspar; brittle; no definite cleavage. G., 4·9.

Uses.—Used as a source of salts of cerium.

Allanite (Orthite).—Complex silicate of cerium, lanthanum didymium, aluminium, iron, and calcium. Cerium oxide 2-18 per cent. In tabular or acicular crystals or massive. Black, brown, green, grey, or yellow opaque; hard; brittle. G., 4·0.

Uses.—Used as a source of salts of cerium.

CHROMIUM.

This metal was discovered at the end of the 18th century, but is still, in its pure form, only of scientific interest. It is a very hard and infusible metal, of a white colour, and of the same weight as cast iron. It is not easily affected by the atmosphere.

Chromium does not occur in nature in the metallic state, but, in combination with silica, occurs in small quantities in all igneous rocks. It is found at times in lead lodes in the form of crocoite, a yellow chromate of lead. The only workable ore of chromium is chromite, which is invariably found as scattered grains, pockets, or veins in the basic igneous rocks known as peridotite and serpentine. Turkey and New Caledonia are the most important source of chrome ore.

Pure metallic chromium is not produced commercially, but impure chromium and an alloy of chromium and iron, ferro-chromium, obtained by smelting chromite, are largely used as constituents of hard steel for rails, machine tools, safes, projectiles, and the wearing parts of crushing machinery.

The most important manufactured compounds of chromium are the chromates and bichromates of potash and soda, which are extensively used for tanning and dyeing, and to a minor extent in the manufacture of matches, in generating electricity, and in purifying oils and spirits. Chromium sesquioxide is used as a pigment. Chrome alum, sulphate of chromium and potash, is used in dyeing, calico printing, and tanning, and also in rendering gum and glue insoluble for water-proofing.

Chromite or Chrome Iron Ore.—Chromite of iron $FeOCr_2O_3$. Chromium, 47 per cent.; chromium sesquioxide, 68 per cent. Sometimes crystallised; usually massive, granular, or compact. Black, opaque, massive. Lustre, metallic to glassy; hard; brittle. G., 4·4.

Uses.—Extensively used for the manufacture of chromates and other salts, and for smelting into ferrochromium. Within the last few years a new use has been found for the mineral in its raw state, namely, as a lining for reverberatory copper and steel smelting furnaces, the life of which is thereby increased two or three-fold. Already the demand for this purpose has reached important proportions. A still later use is in the production of "Silichromite," a material used as a substitute for emery. The commercial value of chrome ore depends almost entirely upon the percentage of chromium sesquioxide present in it, ore under 50 per cent. being marketed with difficulty. The usual market grade is from 50 to 55 per cent., up to which standard the ore is concentrated by hand picking or jigging. For furnace lining the ore should be in fair sized lumps with little or no dust.

1758.—Chromite, Gobarralong, N.S.W. High grade ore.
1759.—Chromite, Gobarralong, N.S.W. Low grade ore.
1760.—Chromite in Serpentine matrix, Gobarralong, N.S.W.

COBALT.

Cobalt is a somewhat rare metal which has been known for about a century and a-half, but for which very few uses have been found. It is a bluish-white hard metal, which takes a good polish, unaffected by the air. It is magnetic, malleable, and, when hot, very ductile. Its weight is about that of copper.

Cobalt does not occur in nature in the metallic state. Its chief ore is asbolite, an oxide of manganese and cobalt. It is also frequently found as the arsenide, smaltite, and sulpharsenide, cobaltite. More or less cobalt occurs in most nickel ores, and in most cases is recovered as a bye-product. Cobalt occurs in many other minerals which, however, owing to their rarity, do not constitute ores of the metal. Descriptions will be found in any text book of Mineralogy.

Metallic cobalt is only used for electroplating, and for that but rarely, though it is said to be superior to nickel for that purpose. Black oxide of cobalt is used in the preparation of sundry pigments, principally smalt, but also cobalt blue, green, yellow, and violet-bronze. Smalt is commercially the most important artificial compound of cobalt. It is a silicate of this metal and potassium having a very fine and permanent blue colour. It is used for blueing paper, linen, and starch, and for colouring and painting on glass and porcelain and for enamels. Cobalt nitrate is used as a chemical re-agent and for making invisible inks.

Asbolite.—Hydrous oxide of manganese and cobalt. Cobalt oxide, 1 to 32 per cent.; nickel, trace to 10 per cent.; manganese dioxide, 50 to 70 per cent. Black or dark-grey, opaque, massive, or stalactitic. Very soft to hard. G., 4·0. Usually occurs in irregular masses amongst the decomposition products of basic igneous rocks.

Uses.—The chief source of cobalt and its compounds. Its value is enhanced by the presence of a high percentage of manganese dioxide, since the ore can then be used for the production of chlorine and the cobalt and nickel subsequently recovered from the liquors. For export, ore should be dressed to at least 4 per cent. by washing, to remove some of the associated clay. Nickel in small proportions depreciates the value of the ore, in larger proportions enhances it.

1577.—Asbolite in Clay, Kanowna.

1801.—Asbolite, Boulder.

2956.—Asbolite, Kalgoorlie.

Smaltite.—Arsenide of cobalt, $CoAs_2$. Cobalt, 8 to 24 per cent.; nickel, trace to 8 per cent. Crystallised or massive. Metallic, white to grey, often tarnished. Hard; brittle. G., 6·5. Occurs in veins of quartz, etc.

Uses.—A minor source of cobalt (and nickel).

T. 114.—Smaltite, Cornwall, England.

Cobaltite.—Sulpharsenide of cobalt, CoAsS. Cobalt, 9 to 34 per cent.; nickel, trace to 3 per cent. Crystallised or massive. Metallic, white, reddish, grey. Hard, brittle. G., 6·1.

Uses.—A minor source of cobalt and its compounds.

T. 116.—Massive Cobaltite, St. Just, England.

T. 117.—Crystallised Cobaltite, Tunaberg, Sweden.

COPPER.

Copper is one of the few metals that has been known to man and utilised by him since prehistoric times. This is partly because it is somewhat frequently found native, and partly because its surface ores are readily reduced to the metal by smelting.

Copper is a very tough red metal, highly ductile and malleable. It is, after silver, the best known conductor of electricity and heat. It is not readily attacked by air or water. Its specific gravity is 8·9.

As already stated, metallic copper occurs native in many parts of the world, especially on the shores of Lake Superior. It also occurs as an important constituent of a vast number of mineral compounds, only a few, however, of which occur in large deposits. These are the two oxides, cuprite and tenorite; the two hydrated carbonates, malachite and azurite; the simple sulphides, chalcocite and covellite; the sulphides of copper and iron, chalcopyrite and bornite; and, finally, fahl-ore or tetrahedrite, a sulphide of copper, antimony, and arsenic.

Ores of copper are chiefly found in veins or lodes in crystalline rocks, slates, and sandstones; but also as impregnations in sedimentary beds, volcanic ash, etc.

Electrolytic refining is now carried out with such success that commercial copper contains less than one-tenth of one per cent. of impurities. Its chief uses are in making wire for electric conductors, and in making alloys. Smaller quantities of the metal are used for a multitude of purposes, including the manufacture of various utensils and apparatus, boiler tubes, nails, sheet-copper for roofing, battery plates, pile-sheathing, and ship-sheathing, etc.

The most important alloy of copper is brass, a variable mixture of copper and zinc, one variety of which, known as muntz-metal, is extensively used for sheathing ships and piles. Copper is also the main constituent of bronze, gun-metal, aluminium bronze, and German silver. Copper is invariably added to gold and silver in coinage, jewellery, and plate to harden them.

Of artificial compounds of copper, the most important is bluestone (copper sulphate) used in extracting silver from its ores, in generating electricity, in dyeing and printing, as an insecticide, etc. Several compounds of copper are used as pigments, yielding various shades of green, blue, and purple.

Copper (Native).—Practically pure copper with traces only of silver, bismuth, etc. In crystalline or irregular masses often coated with cuprite or malachite. Red, opaque, metallic. Soft, tough, malleable. G., 8·9.

Uses.—An important source of commercial copper.

1167.—Native Copper, Geraldine.

Cuprite.—Red oxide of copper, Cu_2O. Copper, 88 per cent. Crystalline, massive or granular. Bright or dark red, translucent or opaque. Soft, brittle. G., 6·0.

Tile Ore.—A massive red variety of cuprite, containing oxide of iron intimately mixed with it. Copper, 50 to 80 per cent.

Uses.—An important ore of copper. The value of this ore, as of all others, depends primarily upon the percentage of copper present; secondly, upon the quantity of associated silver and gold; thirdly, upon the nature of the accompanying impurities and gangue. Of impurities bismuth is the most objectionable, and arsenic and antimony next. Other things being equal, that ore is the most valuable the gangue of which contains such a proportion of silica, lime, and iron oxide as to be self-fluxing or nearly so.

T. 58.—Cuprite, Cornwall, England.
5303.—Cuprite, Ravensthorpe.
1617.—Tile Ore, Croydon, W. Pilbarra G.F.

Tenorite.—Black oxide of copper, CuO, frequently mixed intimately with more or less chalcocite (CuS). Copper, 80 per cent. Scaly, massive, or earthy. Black, metallic or dull. Soft. G., 6·0.

Uses.—*See* Cuprite.

1816.—Tenorite, Rothesay.

Malachite.—Hydrated carbonate of copper. Copper, 57 per cent. Crystallised or, more commonly, massive, stalactitic, radially fibrous, or earthy. Bright green, opaque. Soft, brittle. G., 4·0.

Uses.—*See* Cuprite. Some varieties are sufficiently beautiful when cut and polished to be used for inlaying and other ornamental work.

3707.—Fibrous Malachite, Whim Creek.
1508.—Massive Malachite, Whim Creek.
2507.—Malachite Stockwork in sandstone, Arrino.

Azurite.—Hydrated carbonate of copper. Copper, 55 per cent. Crystalline, massive, compact, or earthy. Azure-blue, transparent to opaque. Soft, brittle. G., 3·8.

Uses.—*See* Cuprite.

4025.—Crystallised Azurite, Northampton.
4011.—Azurite, Narra Tarra.

Chalcocite.—Black sulphide of copper, Cu_2S. Copper, 80 per cent. Crystallised, massive, compact, or granular. Black, metallic, opaque. Soft, brittle. G., 5·7.

Uses.—*See* Cuprite.

2352.—Massive Chalcocite, Murrin Murrin.
3792.—Massive Chalcocite, Arrino.

Covellite.—Indigo sulphide of copper, CuS. Copper, 66 per cent. Crystallised or massive. Indigo-blue, submetallic, or dull, opaque. Very soft and brittle. G., 4·6.

Uses.—*See* Cuprite.

Chalcopyrite (Copper pyrites).—Sulphide of copper and iron, $CuFeS_2$. Copper, 34 per cent. Crystallised or massive. Brass-yellow, metallic, opaque. Sometimes tarnished or iridescent. Soft, brittle. G., 4·2.

Uses.—*See* Cuprite.

1814.—Chalcopyrite, Rothesay.
4033.—Chalcopyrite, Northampton.

Bornite.—Sulphide of copper and iron, Cu_3FeS_3. Copper, 55 per cent. Often intimately mixed with chalcopyrite or chalcocite, the copper contents then varying from 50 to 70 per cent. Crystallised, or massive, granular or compact. Usually iridescent. On fresh fracture copper-red to brown, but rapidly tarnishing. Metallic, opaque. Soft, brittle. G., 5·2.

Uses.—*See* Cuprite.

T. 52.—Bornite, South Australia.

Tetrahedrite (Fahl-ore). — Sulphide of copper and antimony, with variable amounts of arsenic, bismuth, iron, zinc, lead, silver, or mercury. Copper, 15 to 44 per cent.; silver, strong trace to 31 per cent. Crystallised or massive, compact or granular. Grey to black, metallic, brilliant, opaque. Soft, brittle. G., 4·7.

Uses.—*See* Cuprite. A very valuable ore owing to the constant presence of a notable amount of silver, which usually more than compensates for the presence of such objectionable constituents as bismuth, arsenic, and antimony.

5548.—Tetrahedrite, Ravensthorpe Range.

GOLD.

From the very earliest times gold has been known and valued for its great beauty. When pure it is a very soft yellow metal susceptible of a brilliant polish and untarnished by exposure to air, water, or most chemicals. It is the most malleable and ductile of all metals, as well as one of the heaviest, its specific gravity being 19·3.

Gold is but rarely found in nature in a state of great purity, the so called native gold being an alloy of this metal with more or less silver, seldom containing more than 95 per cent. of the pure metal.

This alloy is by far the most common source of the metal. Gold also occurs in nature alloyed with mercury as native amalgam, and in combination with tellurium and silver in various telluride ores, chiefly calaverite, sylvanite, and petzite. Gold also occurs in minute invisible specks scattered through many samples of pyrites, copper ores, etc., and can frequently be extracted from these ores at a profit owing to the great value of the metal and the high pitch of perfection to which its metallurgy has attained.

Native gold occurs in veins or lodes, or disseminations in crystalline and other rocks, as well as in alluvial deposits, river gravels, etc. The telluride ores occur only in veins or lodes below the zone of complete oxidation.

Pure gold is chiefly used as a surface covering or plating to ornaments and utensils of other metals. It is also used extensively for stopping teeth. When beaten out into leaf it is used for ornamental painting and lettering. For other purposes gold is hardened by being alloyed with copper or silver or both, such alloys being used for coinage, jewellery, plate, etc. The most useful artificial compound of gold is the chloride, which is used in photography and in the manufacture of ruby glass. Purple of Cassius is a compound containing gold and tin, and is used in making ruby glass.

Gold (Native).—Gold alloyed with more or less silver. Gold 50 per cent. to 99 per cent.; silver, trace to 50 per cent. Varieties containing over 30 per cent. of silver are known as *Electrum*. Crystallised, dendritic, massive, granular, spongy, in flakes, and in rolled grains and nuggets. Opaque, metallic, yellow of various shades. Soft, malleable. G., 14 to 19.

Uses—The chief source of gold and its compounds.

3696.—Crystallised Gold in Asbolite, Kanowna.
1238.—Dendritic Gold, Donnybrook.
419.—Massive Gold, Peak Hill.
3712.—Granular Gold, Boogardie.
1503.—Sponge Gold, Boulder.
2499.—Flake Gold, Kalgoorlie.
1915.—Alluvial Gold, Greenbushes.

Calaverite.—Telluride of gold, $AuTe_2$. Gold, 34 to 42 per cent.; silver 0·5 to 5 per cent. Massive, metallic, brilliant. White to yellow, opaque. Soft, brittle. G., 9·2.

Uses—A source of gold and its compounds.

144.—Calaverite, Boulder.

Krennerite.—Telluride of gold and silver. $(AuAg)Te_2$. Gold, 34 to 37 per cent.; silver, 3 to 6 per cent. Crystallised, with perfect cleavage. White to yellow, metallic, brilliant, opaque. Soft, brittle. G., 8·2.

Uses.—A source of gold and silver and their compounds.

87.—Krennerite, Boulder.

Sylvanite.—Telluride of gold and silver. $(AuAg)Te_2$. Gold, 26 to 30 per cent.; silver, 8 to 13 per cent. Crystallised, arborescent, beaded or massive, with a perfect cleavage. White, grey, or yellow. Metallic, brilliant, opaque. Very soft, brittle. G., 8·1.

Uses.—A source of gold and silver and their compounds.

Petzite.—Telluride of gold and silver $(AgAu)_2Te$. Gold, 18 to 26 per cent.; silver, 40 to 47 per cent. Massive, granular, or compact. Black, metallic, brilliant, opaque. Soft. G., 8·9.

Uses.—A source of gold and silver and their compounds.

1806.—Petzite, Boulder.

Nagyagite.—Sulphotelluride of gold, lead, and antimony. Gold, 6 to 13 per cent.; silver trace to 2 per cent. In tabular crystals with perfect cleavage, and massive, granular, or foliated. Lead-grey, metallic, brilliant, opaque. Very soft. G., 7·0.

Uses.—A rare source of gold and silver and their compounds.

IRON.

Of all the metals that have been pressed into the service of man, iron is by far the most common and most useful, and was first utilised in prehistoric times. The chemically pure metal is not an article of commerce. It is a white metal capable of taking a high polish. It is somewhat harder than copper, and considerably stronger; it is malleable, and at a red heat can be welded. Iron can only be melted at a dazzling white heat; when heated somewhat and cooled suddenly it does not harden. Iron does not tarnish in perfectly dry air, but in moist air or water rapidly rusts. Salt water and weak acids attack it rapidly.

Iron appears in commerce in three states of varying purity, known respectively as wrought iron, steel, and cast iron. All these forms of iron contain as impurities carbon, silicon, phosphorus, sulphur, and manganese, and it is upon the relative proportions present of these elements, especially carbon, that the quality of the metal depends. Wrought iron is the purest form of commercial iron, and contains essentially from ·03 to ·40 per cent. of carbon. It closely resembles pure iron in its properties, but is slightly more fusible and less malleable than the latter. Steel contains, in addition to the usual impurities of all forms of iron, an amount of carbon varying from ·4 per cent. to 1·5 per cent. It differs from wrought iron in being less malleable and less easily welded, more fusible, and stronger. Its most striking feature is its capacity for becoming extremely hard when heated and suddenly chilled. Cast iron contains from 1·5 to 5 per cent. of carbon and comparatively large quantities of sulphur, phosphorus, and silicon. It melts more easily than steel, is brittle when cold, and does not harden on heating and quenching.

Iron occurs in abundance in nature in many forms (very rarely as the metal), being an important constituent of almost all rocks.

The only native compounds, however, that can be profitably employed as a source of the metal are the oxides, magnetite, etc., and the carbonate, siderite.

Pure iron, as already stated, is not used in the arts; the purest wire used for piano strings, etc., still containing 0·3 per cent. of impurities. Wrought iron is used for a multitude of purposes, chiefly for forged parts of machinery, boiler plates, pipes for water, gas, etc., girders and other structural members, roofs, etc. Steel has largely replaced wrought iron for many purposes. Its chief uses are for rails, ships, bridges, parts of machinery, and structures of various kinds, etc. Cast iron is made mainly as an intermediate product in the manufacture of steel and wrought iron. It is also largely used for casting various machine details and industrial and domestic utensils.

The chief alloys of iron are those varieties of steel containing various proportions of manganese, nickel, and rarer metals. These are for the most part harder and stronger than ordinary steel. Various cast alloys of iron with manganese and other metals are produced solely for the production of the special steels above mentioned. Chief of these are spiegel and ferro-manganese, alloys of manganese and iron with considerable carbon, used in the manufacture of Bessemer steel, Hadfield's manganese steel, etc.

Compared with the metal itself, the artificial compounds of iron are of minor importance. Artificial ferric oxide is employed as a pigment and polishing powder (rough). The hydrate, carbonate, and other salts are used in medicine. An artificial mixture of the oxides (iron-scale) is used in the conversion of cast iron into wrought iron and steel. Ferrous sulphate (copperas) is used to precipitate gold, and in the manufacture of Nordhausen sulphuric acid, iron mordants, inks, etc. Prussian blue, a cyanide, is a valuable pigment. Potassium ferrocyanide is used as a source of potassium cyanide and as a chemical re-agent.

Magnetite.—Magnetic oxide of iron, Fe_3O_4. Iron, 65 to 72 per cent. Crystallised or massive, granular or compact. Black, metallic, opaque. Magnetic, hard, brittle. G., 5·1. Occurs as irregular masses in volcanic rocks, and as lodes in schists.

Uses.—The richest and purest ore of iron, used largely for the production of the commercial metal, and to a slight extent as a flux in lead and copper smelting. Bulk samples of ore contain various impurities, which mostly exert a marked effect upon the final smelted metal, and, hence, influence to a very large extent the value of a deposit. The chief of these are phosphorus, sulphur, silica, and titanic oxide.

Phosphorus.—This element, in more than traces, is the most objectionable constituent of an iron ore. Ores containing more than ·045 per cent. of phosphorus are practically useless for the production of Bessemer steel. Basic steel (Thomas steel) can be made most profitably from ores containing from 0·4 to 2·0 per cent. phosphorous. Intermediate ores are best suited for the production

of wrought iron, and grey and white iron for castings. With ores rich in iron a slightly higher percentage of phosphorus is permissible than with poor ores.

Sulphur.—This element is not so objectionable as phosphorus. The best ores contain less than 0·05 per cent. of this element. Inferior ores contain up to 2·0 per cent., and are frequently roasted to remove this sulphur before smelting.

Silica.—Small amounts of this under 5 per cent. are no drawback to the ore, beyond that amount the less the better since the more silica contained in the ore the more lime is needed to flux it. If the ore contains lime or alumina this will serve to neutralise the bad effect of an increased content of silica. For iron smelting the best ores contain not more than 10 per cent., poorer ores 10 to 30 per cent. For fluxing lead or copper ores the silica must not exceed 7 per cent.

Titanic Oxide.—This constituent is usually stated to cause considerable difficulty in the smelting of pig-iron, and most iron smelters look askance at ores containing more than 0·5 per cent. Lump ores, however, containing up to 40 per cent. TiO_2 have been smelted in both England and the United States without causing any difficulty, so that apart from the concurrent decrease in the iron content the presence of a notable percentage of titanium can only be considered a drawback by prejudiced persons, so long as the ore is massive and not in the state of fine sand. In fluxing lead and copper ores titanic oxide acts like silica, and the total of these two constituents should not therefore exceed 7 per cent., whilst the titanic oxide alone should be under 5.

Other Constituents.—Manganese oxide in small quantities increases the value of an iron ore for all purposes. Lime and alumina to the extent required for fluxing the silica of the ore are also an advantage.

5545.—**Magnetite Crystals, Eastern Goldfields.**
784.—**Magnetite (Granular Massive), Collie.**

Hæmatite.—Oxide of iron, Fe_2O_3. Iron, 67 to 70 per cent. Crystallised, massive granular, columnar or stalactitic, earthy, micaceous. Earthy variety red, soft to hard, dull, opaque. Other varieties black, metallic, hard, opaque, brittle. G. 5·1.

Uses.—An important source of iron. (*See* remarks under Magnetite.)

T. 145.—**Crystallised Hæmatite, Elba.**
5356.—**Granular massive Hæmatite, Wilgi Mia, Weld Ranges.**
4359.—**Massive Hæmatite, near Mullewa.**
48.—**Micaceous Hæmatite, Boulder.**

Limonite.—Hydrated oxide of iron, $2Fe_2O_3.3H_2O$. Iron, 57 to 60 per cent. Stalactitic, fibrous, concretionary, massive or earthy. Brown or yellow, sometimes iridescent, opaque. Soft or hard. Brittle.

The *Laterite Ore* (surface clay ironstone) of Australia and India is a mixture of limonite with more or less bauxite (aluminium ore) and sometimes some hæmatite, gothite, or other hydrated oxides of iron. It is concretionary or cellular, massive, and contains up to 62 per cent. of iron.

Uses.—An important source of iron. (*See* remarks under Magnetite.)

The soft earthy yellow varieties known as *Ochre* contain more or less clay and are used largely for the production of pigments and giving a body to linoleum or oilcloth. For this purpose the value of the ore depends upon the fineness of its grain, its freedom from grit and its colour both fresh and when calcined.

Concretionary limonites and laterites are largely used for ballasting roads and railways.

1408.—Massive Limonite, Greenhills.
101.—Fibrous Limonite, Mt. Jackson.
498.—Limonite stalactite, Mt. Morgan, Queensland.
996.—Limonite (Laterite), Wongan Hills.
T. 166.—Limonite (Yellow Ochre), South Australia.

Siderite (Spathic iron ore).—Carbonate of iron, $FeCO_3$. Iron, 40 to 48 per cent. Crystallised, massive granular, fibrous, compact, earthy. Grey, yellow, or brown, translucent to opaque. Soft, brittle. G., 3·8.

The *Clay-band Ironstone* of England is an impure siderite containing much clay. The *Black-band Ironstone* of Great Britain and America is a siderite mixed with much coaly matter.

Uses.—An important ore of iron. (*See* remarks under Magnetite.)

T. 183.—Siderite, West Prussia.
T. 186.—Clay-band Ironstone, Staffordshire, England.

Franklinite.—Oxide of iron, zinc, and manganese. Iron, 40 to 60 per cent.; manganese, 8 to 18 per cent.; zinc, 5 to 18 per cent. Crystallised, massive, granular, or compact. Black, opaque, metallic or dull. Hard, brittle, slightly magnetic. G., 5·1.

Uses.—After recovering the zinc the residue is smelted with the production of ferro-manganese. For impurities and their effects see under Magnetite.

T. 156.—Franklinite, New Jersey, U.S.A.

Ilmenite (Titaniferous Iron Ore).—Oxide of iron and titanium, $FeO.TiO_2$. Iron, 36 to 60 per cent.; titanium, 6 to 31 per cent. Crystallised, massive, in scales or rolled grains. Black metallic, opaque. Hard, brittle. G., 4·7. Occurs largely as beds of black sand on beaches, etc., also mixed with magnetite in irregular masses and lodes in basic igneous rocks.

Uses.—Used as a source of iron, ferro-titanium, and titanium compounds. The fine sandy ore has not yet been successfully

smelted for iron on a large scale. After grinding it is sometimes used as a knife polish and as a pigment for covering metal work.

T. 205.—Massive Ilmenite, Mt. Barker.
5366.—Ilmenite Sand, Bunbury.

Chromite (*see* page 26) is used as a source of ferro-chromium; and **Wolfram** (*see* page 56) as a source of ferro-tungsten.

LEAD.

This was one of the few metals known to man in very ancient times. It is a very soft bluish white metal, which can be readily rolled or pressed into sheet or wire. It rapidly tarnishes on exposure to the air and is then but little affected by air or many acids. It melts below a red heat and has a specific gravity of 11·3.

Occasional grains of metallic lead have been found in nature, but it chiefly occurs as the sulphide, galena. A second common ore is the carbonate, cerussite, whilst much less common are the sulphate, anglesite, and the chlorophosphate, pyromorphite. Ores of lead usually occur in veins and lodes in crystalline rocks, slates and limestones.

Commercial lead is extremely pure and is largely used in sheets for roofing and making pipes. It is also used for bullets and for making white lead, red lead, litharge, etc. Lead hardened with a few per cent. of antimony is used for coffins and for lining acid chambers, etc. Of lead alloys the most important is that with tin, known as solder, and that with tin and antimony, known as type metal. Fusible alloys and antifriction alloys contain a large proportion of lead.

Of the artificial compounds of lead, by far the most important is white lead, a basic carbonate, which is the most useful pigment known. Red lead, an oxide, is also a valuable pigment, and is used in the manufacture of flint glass. Litharge, another oxide, is used as pigment, as a constituent of many varieties of glass and of glazes for clay-ware, and in manufacturing white lead. Lead chromate is used as a pigment, as also lead sulphate.

Lead ores are used almost solely as a source of the metal from which, after refining, the various artificial compounds are prepared. Two other minor, though still important, uses they are put to. One is in the metallurgy of the precious metals, the ores of these being smelted with ores of lead, to form the so-called base bullion, or pig lead containing all the gold and silver in solution in a convenient concentrated form for final recovery. The second use is in the production of lead fume, a fine mixture of lead sulphate and oxide used as a pigment.

Galena.—Sulphide of lead, PbS. Lead, 83 to 86 per cent.; silver, trace to 3 per cent. Crystallised with cubic cleavage or granular massive. Lead grey, metallic, opaque. Soft, brittle. G., 7·5.

Uses.—The main source of metallic lead. Also used as a source of lead fume and in recovering gold and silver from their ores. The value of the ore depends upon the amount of lead and silver present. The best bulk ores contain less than 5 per cent. of zinc, as this metal causes trouble in smelting, and not more than a trace of antimony and arsenic.

4002.—Crystallised Galena; Narra Tarra.

1524.—Galena, Andover.

Cerussite.—Carbonate of lead, $PbCO_3$. Lead, 77 per cent.; silver, traces. Crystallised or granular or compact massive. White or grey, transparent to opaque. Soft, very brittle. G., 6·5.

Uses.—An important ore of lead. On value, *see* remarks under Galena.

T. 83.—Crystallised Cerussite, Cumberland, England.

4007.—Massive Cerussite, Narra Tarra.

Anglesite.—Sulphate of lead, $PbSO_4$. Lead, 66 to 68 per cent.; silver, traces. Crystallised or massive, granular compact or stalactitic. White or tinted, transparent to opaque. Soft, very brittle. G., 6·2.

Uses.—A common ore of lead. On value, *see* remarks under Galena.

411.—Anglesite with Galena, Gorge Creek.

Pyromorphite.—Chlorophosphate of lead. Lead, 62 to 75 per cent.; silver, traces. Crystallised or massive, resinous. Green, yellow or brown, translucent or opaque. Soft, brittle. G., 6 to 7.

Uses.—A minor ore of lead.

1168.—Crystallised Pyromorphite, Geraldine.

33.—Massive Pyromorphite, Narra Tarra.

LITHIUM.

Lithium is one of the alkali metals closely resembling sodium, but of much greater rarity, and was discovered in 1817. It is silver white, softer than lead and extremely light, being only a little over half as heavy as water. It melts at a low temperature and if heated much beyond that point burns steadily with a bright white light. It rapidly tarnishes when exposed to the air.

Lithium does not occur in nature in the metallic state but usually in combination with other metals and silica in granite or in pegmatite veins or dykes.

The metal is not put to any use in the arts. Its most important artificial compounds are the chloride, carbonate, and citrate, all of which are used for medicinal purposes and also as contituents of aerated waters (lithia water, etc.).

Lepidolite (Lithia mica.)—Fluosilicate of lithium, aluminium, and potassium. Lithia (lithium oxide), 4 to 6 per cent.

In scaly granular masses or in large cleavable plates. Pink, amethystine, white, or grey. Transparent or translucent. Soft, tough. G., 2·8.

Uses.—This is the chief source from which lithium salts are prepared, and its value will depend upon the proportion of lithia present in it.

1858.—Lepidolite in radiating scales, Coconarup.

556.—Lepidolite, in large sheets, Londonderry.

Spodumene. — Silicate of lithium and aluminium, $Li_2O.Al_2O_3.4\ SiO_2$. Lithia, $4\frac{1}{2}$ to $7\frac{1}{2}$ per cent. Crystallised or massive, vertical cleavage well marked. Green, sometimes yellow or purple. Transparent to opaque. Hard and brittle. G., 3·2.

Uses.—Same as for lepidolite, which see.

1864.—Spodumene, Ravensthorpe. Large pale green crystals in granite.

MAGNESIUM.

This metal was first separated and described at the beginning of the 19th century, though its compounds had been in use for some time previous to this. It is a soft white metal, which does not tarnish in dry air but is coated with a film of oxide on exposure to moist air. It is easily dissolved by dilute acids. It melts at a red heat and burns readily in the air with a brilliant flame.

Magnesium does not occur native in the earth, but is a universal constituent of all rocks, forming a considerable proportion of serpentine and other basic igneous rocks. Comparatively few minerals are, however, capable of successful treatment for the production of the metal and its artificial compounds. Of these the most important is the carbonate, magnesite; the sulphates, epsomite and kieserite, and the chloride of potassium and magnesium, carnallite, are also valuable minerals. Asbestos, talc and other magnesian silicates are dealt with under the title "Silica and silicates." Magnesium chloride and sulphate are constituents of almost all well and bore waters.

Metallic magnesium in the form of ribbon or powder is burnt to produce a brilliant illumination of interiors, underground hollows, etc., for photographic or show purposes; it is also used for signalling purposes and in pyrotechny. Small quantities are used for various analytical purposes.

Of artificial compounds the most important is the oxide, magnesia, large quantities of which are made into fire brick or pressed direct into the linings of furnaces for the production of "basic" steel, and of kilns for burning hydraulic cement. It is also used as a non-conducting covering for boilers, etc., and as a starting point for the manufacture of various other magnesium compounds. The hydrous sulphate, known as Epsom salts, is

largely used in the manufacture of dyes, soaps, and paints, in tanning leather, and in medicine. The chloride is used in the textile industry and as a source of metallic magnesium, the sulphite in cleaning wood-pulp for paper manufacture.

Magnesite.—Carbonate of magnesium, $MgCO_3$. Magnesium, 25 to 28 per cent.; magnesia, 42 to 47 per cent.; carbon dioxide, 47 to 52 per cent. Occasionally crystallised, usually massive compact granular or earthy. White, yellowish, brownish; transparent to opaque. Soft or hard, brittle. G., 3·1. Occurs in veins in serpentine and other rocks, and in boulders in the weathered rocks.

Uses.—Chiefly burnt to convert it into magnesia, for the manufacture of refractory bricks and furnace linings. For this purpose it should contain a small proportion only of silica. Also used in the manufacture of magnesium chloride, sulphite, and sulphate (Epsom Salts). Large quantities used for the production of carbon dioxide for aerating waters, etc., magnesia or magnesium sulphate being obtained as bye-products. Magnesite used as a source of magnesium salts should be as free as possible from iron and lime.

334.—Magnesite, Coolgardie.

2945.—Magnesite, Kalgoorlie.

Epsomite.—Native Epsom Salts. Hydrous sulphate of magnesium, $MgSO_4.7H_2O$. Magnesia, 16 per cent. Crystallised or in fibrous masses. White or yellowish, transparent to translucent. Very soft, brittle. Soluble in water. G., 1·7. Occurs in sedimentary deposits in ancient or recent lake-beds; common in mineral waters.

Uses.—After purification marketed as Epsom salts, the uses of which are given above.

Kieserite.—Hydrous sulphate of magnesium, $MgSO_4.H_2O$. Magnesia, 29 per cent. Rarely crystallised, usually massive granular or compact. White, or grey; translucent or opaque. Soft, friable or firm. G., 2·5. Occurs in sedimentary beds.

Uses.—An important source of Epsom Salts.

Carnallite.—Hydrous chloride of magnesium and potassium. Magnesium, 8 per cent.; potassium, 14 per cent. Granular massive, rarely crystallised. White or pink, transparent to translucent. Very soft, brittle. G., 1·6. Occurs in beds in sedimentary deposits.

Uses.—Used as a source of metallic magnesium. Also a valuable fertiliser owing to the large percentage of soluble potassium in it. For the latter purpose its value depends entirely upon the percentage of potassium present; for the former purpose the purest mineral is the most valuable.

Dolomite.—*See* page 20.

MANGANESE.

The metal manganese was discovered at the latter end of the 18th century. In its pure form it only appears in commerce as a chemical curiosity. It is a very hard brittle metal, resembling cast iron in appearance and weight, but it is so susceptible to the action of the air that it can only be preserved in sealed bottles or under mineral oil.

Manganese does not occur in nature in the metallic state, but is usually found combined with oxygen as one of the several oxides, which constitute the chief source of the metal. It is also a universal constituent, in small proportion, of all rocks, especially the more basic, darker coloured, igneous rocks occurring in them in combination with silica, but not in such a form as would constitute a commercial source of the metal. Workable deposits of the ores are, however, largely found in close association with such rocks or the debris resulting from their decomposition. Ores are also frequently found in association with limestone, being originally absorbed from the seawater by a living organism and subsequently secreted in the substance of the shells or corals which have gone to build up the beds of rock.

In its pure state manganese has no application in the arts. Of its alloys those with iron are the most important, viz., ferro-manganese, containing from 25 to 75 per cent. of manganese, and spiegel-eisen, containing from 2 to 25 per cent. These alloys are largely used in the manufacture of Bessemer steel. An alloy of manganese, copper and zinc has been used as a substitute for German silver, which it resembles very closely.

Compounds of manganese are used in large quantities for various technical purposes. This is especially true of the dioxide (MnO_2) which occurs in nature in Pyrolusite (*q.v.*). Potassium and sodium permanganates ($KMnO_4$ and $NaMnO_4$) are extensively used as disinfectants and deodorants, owing to the ease with which they give up part of the oxygen contained in them.

The natural oxides of manganese are all used for both colouring and decolourising glass; for colouring pottery and brick; for calico-printing and dyeing; and in manufacturing certain paint. A considerable quantity of manganese is also used as a flux in lead smelting, oxide of manganese in conjunction with oxides of iron and lime forming a readily fusible slag with the siliceous gangue of the lead ore. For fluxing purposes the value of the ore depends upon its richness in manganese and its freedom from silica; iron oxide is not looked upon as an objectionable constituent. The oxides and carbonate are the only ores used as a source of the metal in the form of spiegel or ferro-manganese. For this purpose the ore should be rich in manganese, poor in silica, and contain only very minute amounts of sulphur or phosphorus, both of which tend to reduce the value of the final product, Bessemer steel. A third main use of the natural oxides of manganese is in the production of chlorine, bromine, and iodine. The most important of these is chlorine, which is employed in extracting gold from its ores and

refining it, and in the production of bleaching powder or chloride of lime for bleaching and disinfecting. This is the chief use to which it is put in Australia, the chlorine being produced by heating a mixture of salt and sulphuric acid with any ore of manganese containing the dioxide. For this purpose the value of the ore depends entirely upon the proportion of dioxide present, and is bought at so much "per unit," that is so much for every one per cent. of dioxide (MnO_2) in the ore.

The following are the chief compounds of manganese occurring in nature:—

Pyrolusite.—Dioxide of manganese, MnO_2. Manganese, 60-63 per cent.; manganese dioxide, 95-100 per cent. Soft, black, crystalline or massive, opaque. G., 4·8.

Uses.—This mineral is the most useful ore for the production of chlorine, and the manufacture of permanganates owing to the fact that it is richer in the dioxide than any other manganese ore. It should be noted in this connection that the "pyrolusite" of the Australian miner and ore-dealer includes practically all native manganese oxides such as Psilomelane, etc. Pyrolusite is also used as a flux, as a source of manganese alloys, and for all other purposes mentioned above.

4340.—Pyrolusite, Gladstone, Qld.

Braunite.—Oxide and silicate of manganese $4MnO.3MnO_2.SiO_2$. Manganese, 63 per cent.; silica, 10 per cent.; manganese dioxide, 43 per cent. Crystalline or massive. Black, opaque, hard, brittle. G., 4·8. A somewhat rare ore.

Uses.—Of little use for the manufacture of chlorine owing to the low percentage of the dioxide present. It can be used for all other purposes, but the invariable presence of a considerable percentage of silica makes it an inferior ore under all circumstances.

Manganite.—Hydrated oxide of manganese, $MnO.Mno_2.H_2O$. Manganese, 63 per cent.; manganese dioxide, 50 per cent. Crystallised or massive. Soft, brittle, black, opaque, sub-metallic. G., 4·3.

Uses.—Same as Braunite.

T. 189.—Manganite, Michigan, U.S.A.

Psilomelane.—Hydrated oxide of manganese, $xMnO.MnO_2.yH_2O$. Variable in composition, but averages: manganese 55 per cent., manganese dioxide, 70 per cent.

A common variety of this mineral known as *Asbolite* frequently contains sufficient cobalt and nickel to constitute an ore of those metals, *q.v.*, (massive or concretionary). Variable hardness, black, opaque. G., 3·7 - 4·7. A commonly occurring ore.

Uses.—This ore is used for all the purposes to which Pyrolusite is put, and after that mineral is the most valuable of the manganese ores.

4444.—Psilomelane, Ravensthorpe Range, near Mt. Desmond.

1801, etc.—Asbolite. (*See* Cobalt.)

Rhodocrosite.—Carbonate of manganese, $MnO.CO_2$. Manganese, 48 per cent. (crystalline or massive). Somewhat hard; pink, grey, or brown; semi-opaque. An uncommon ore. G., 4·4.

Uses.—Can be used as a flux or as a source of the metal.

T. 195.—Rhodocrosite, Colorado, U.S.A.

MERCURY.

Mercury is the only metal which at ordinary temperatures is liquid. It was known some centuries before the Christian era. It is a bright, metallic, white, mobile liquid, which does not tarnish in the air, and readily dissolves gold, silver, and many other metals. Its specific gravity is 13·5.

Mercury is found native in small globules, but its commonest native compound and chief ore is the sulphide, cinnabar. It also occurs as the telluride, coloradoite, and in some varieties of fahl-ore, but neither of these minerals are sufficiently plentiful to constitute sources of the metal. Mercury ores usually occur in veins or stock-works in slate, limestone, or igneous rocks.

By far the greater part of the world's production of mercury is employed in extracting gold and silver from their ores. Smaller quantities are used in the electrolytic production of caustic soda, for thermometers, barometers, battery zincs, etc., and the production of amalgams, or alloys of mercury with other metals. Sodium amalgam is added to ordinary mercury to make it dissolve gold more actively, and is also used as a reducing agent in preparing various organic products. Tin amalgam is used as a backing for glass to produce an ordinary mirror. Various amalgams are used in dentistry as stopping for teeth. Mercurous chloride, or calomel, is used in medicine; mercuric chloride, or corrosive sublimate, as an antiseptic and vermicide, especially for preserving timber, also in making aniline-red, in dying and calico-printing, and in etching steel plates. Mercuric sulphide or vermilion is an important pigment. Several mercury salts are employed as analytical re-agents and in medicine. Mercury fulminate is an extremely explosive salt used for detonators and percussion caps. Mercuric oxide is sometimes used in anti-fouling paint for ships' bottoms.

Mercury (Native).—Practically pure mercury. In small liquid globules, white, metallic, brilliant. G., 13·6.

Uses.—A minor source of the metal and its compounds.

Cinnabar.—Sulphide of mercury, HgS. Mercury, 86 per cent. Crystalline, granular, massive, or earthy. Red, sometimes brownish or leaden; transparent to opaque. Lustre, brilliant to dull. Soft, slightly sectile. G., 8·1.

Uses.—The main source of the metal and its compounds. Ores as low as 0·3 per cent. have been worked at a profit, though 1 to 3 per cent. is the usual smelting grade.

T. 34.—Cinnabar, California, U.S.A.

MOLYBDENUM.

This rare metal, first discovered in 1780, is very similar to silver in appearance, but is somewhat harder, lighter, and more infusible. It is not affected by the air at ordinary temperatures, and resists the action of many acids. In spite of its many useful properties, it has not yet found any application in the arts except in combination with other metals, etc.

The commonest ore of molybdenum is the sulphide, molybdenite, the metal itself not occurring uncombined in nature. The oxide, molybdite, sometimes occurs near the surface in sufficient quantities to constitute an ore. The usual matrices of both these minerals are veins of quartz or calcite traversing igneous rocks. Ores of copper, bismuth, etc., usually accompany them.

Crude molybdenum, containing carbon and iron, is obtained by the electric smelting of the roasted ores, and ferro-molybdenum, an alloy of iron and molybdenum, by adding iron ores to the smelting mixture. A considerable demand for these products has arisen since the discovery that the addition of a little of either of them to chrome steel renders it self-hardening. In this respect it is said to be better than tungsten.

Ammonium molybdate is used largely in analytical work for the estimation of phosphorus. Molybdenum tannate is a useful dye for leather, producing, in conjunction with logwood, various shades of yellow and brown. In pottery molybdenum blue or blue carmine is used to impart a blue colour of great brilliancy and durability. Compounds of this metal are also used for dyeing silk blue. Sodium molybdate has been used in the treatment of dropsy.

Molybdenite.—Sulphide of molybdenum, MoS_2. Molybdenum, 60 per cent. Foliated, scaly, or sometimes granular. Metallic, opaque, lead coloured, closely resembling graphite. Very soft. G., 4·7.

Uses.—This is the chief source of the crude metal and its alloys and salts. The ore to be saleable must be concentrated by hand or machinery up to at least 45 per cent. of metal, and must be entirely freed from copper compounds. The Elmore process of oil concentration has been found successful in some cases.

1316.—Molybdenite in vein quartz, Clackline.
387.—Molybdenite in amphibolite, Coolgardie.
4353.—Molybdenite in quartz, Chowey Creek, Mt. Shamrock, Queensland.

Molybdite.—Oxide of molybdenum, MoO_3. Molybdenum, 66 per cent. In fine crystals, fibrous, massive, or earthy. Yellow. Very soft. G., 4·5.

Uses.—This is much rarer than molybdenite, but, as it contains more of the metal and requires no roasting to remove sulphur, it would be somewhat more valuable but for the difficulty of concentrating it. (*See* remarks under molybdenite.)

NICKEL.

This useful metal has been known for about a century and a half, but has only within the last few years been extensively used in the arts. It is a bright, greyish-white metal; hard, ductile, and malleable. It is capable of taking a very high polish, which is not easily dulled by air or water. It is magnetic.

Nickel does not occur native, though an alloy with iron forms the chief constituent of many meteorites. Its chief ores are garnierite, a silicate of nickel and magnesium found chiefly in New Caledonia, and nickeliferous pyrrhotite, a sulphide of iron and nickel. Of minor importance are the sulphide, arsenide, and arsenate described below. A great number of other minerals are known which contain nickel, any of which, if found in sufficient quantity, would form a valuable source of the metal. They appear, however, to be very rare, and are not therefore described here. Descriptions will be found in any text book of Mineralogy. Nickel occurs to a slight extent in all cobalt ores, and cobalt in all nickel ores. The ores occur usually in association with basic igneous rocks.

The most important use of nickel is in making various alloys, but the pure metal is largely used for various metal instruments, ornaments, and other articles, as well as for plating such articles when made of cheaper metals. By far the most important alloys of nickel are those with steel, which is thereby rendered much stronger, harder, more elastic and less liable to corrosion. Such steels are extensively used for armour plate, projectiles, heavy guns, propeller-shafts, railway axles, etc. The nickel is added to the steel either in the form of the pure metal, or one of the alloys ferro-nickel, chrome-nickel, tungsten-nickel, or molybdenum-nickel, whose names indicate their composition. Alloys of nickel and copper in various proportions are used in many countries for coinage. An alloy of nickel, copper, and zinc, known as "German Silver" is extensively used for various implements and ornaments.

Nickel oxide is used to add to steel for making nickel-steel. Nickel ammonium sulphate in solution for nickel-plating.

Garnierite.—Hydrous silicate of nickel and magnesium. Nickel, 43 to 48 per cent; cobalt, trace to ·5 per cent. Massive, clay-like. Dark or pale green, or chocolate; opaque, dull. Very soft. G., 2·5. Occurs in veins and stockworks in serpentine and peridotite.

Uses.—One of the chief sources of the metal and its compounds. Ores practically free from cobalt are the most valuable. For market the ore should be hand picked up to a minimum of 7 per cent.

4350.—Green Garnierite, New Caledonia.

Nickeliferous Pyrrhotite.—Sulphide of iron and nickel. $(FeNi)_7.S_8$. Nickel, 0·5 to 10 per cent; cobalt, trace to 0·5 per cent. Metallic, massive, or crystallised. Bronze-brown, opaque, magnetic. Soft, brittle. G., 4·6. Occurs in veins with quartz, etc. in basic igneous rocks.

Uses.—An important source of nickel and its compounds. The freer the ore from cobalt the more valuable it is. For smelting, the ore should be dressed to a minimum of 2 per cent. nickel.

1415.—Nickeliferous Pyrrhotite, Southern Cross.

T. 122.—Nickeliferous Pyrrhotite, Sudbury, Canada.

Millerite.—Sulphide of nickel, NiS. Nickel, 64 per cent. In fine crystals or radiated massive. Metallic, yellow or brown, opaque. Soft, brittle. G., 5·5. Found in veins of quartz or calcite.

Uses.—A minor source of nickel owing to its rarity.

T. 124.—Millerite, Pennsylvania, U.S.A.

Niccolite (Kupfernickel).—Arsenide of nickel, NiAs. Nickel, 33 to 44 per cent. Massive, metallic. Light copper colour, opaque, tarnishes readily. Hard, brittle. G., 7·5. Found in veins of quartz or calcite.

Uses.—*See* Millerite.

T. 119.—Niccolite, Bebra, Saxony.

PLATINUM, IRIDIUM, AND OSMIUM.

These are all rare metals resembling one another closely and found closely associated in nature, they will therefore be dealt with together.

Platinum is a bright, greyish, white, malleable, and ductile metal. It is very infusible and not readily acted on by the strongest acids. At a red heat platinum can be welded with ease. Its specific gravity is 21·5. Its chief use is in the manufacture of chemical ware such as vessels for the concentration of acids, weights, etc. Other important uses are in the manufacture of platinotype photographic paper, and in various electrical appliances. Besides this it is used in jewellery, in physiological and surgical instruments and in dentistry, and in the "Contact Process" of manufacturing sulphuric acid. Alloyed with iridium it is not only used for chemical ware, but also for standard weights and measures, etc. Platinum tetrachloride is used as a chemical re-agent.

Iridium is a hard, white, brittle metal, extremely heavy, its specific gravity being 22·4. It is not used uncombined in the arts, but from 5 to 10 per cent. is frequently alloyed with platinum, which is rendered much harder and more durable thereby. Iridium oxide is used in porcelain painting. An alloy with osmium is used for compass bearings and for tipping pens.

Osmium is an extremely hard, bluish metal, insoluble in all acids, even *aqua regia*. It is one of the heaviest substances known, having a specific gravity of 22·5. Its chief use is in incandescent electric lights, for which it is the most efficient material yet experimented with. It is also used in alloys with iridium, as described above. Osmium oxide is used as a black stain in optical apparatus.

These three metals are almost always found in nature together, rarely in lodes, more frequently in river or beach sands in the form of native platinum, native iridium, and osmiridium. The only native compound of these metals of any importance is the arsenide of platinum, sperrylite.

Platinum (Native).—Platinum alloyed with iron, iridium, etc. Platinum, 50 to 86 per cent.; iridium, trace to 20 per cent.; osmium, trace to 10 per cent. In small grains or scales, occasionally in large nuggets. Greyish white, bright, metallic, malleable, soft, sometimes magnetic. G., 14 to 19.

Uses.—The chief source of platinum and its compounds, and to a minor degree, of iridium and osmium.

5192.—Platinum Sands, Clarence River, N.S.W.

Iridium (Native).—Iridium alloyed with platinum, etc. Iridium, 30 to 76 per cent.; platinum, 20 to 55 per cent.; osmium, trace. In angular white metallic grains. Slightly malleable, hard. G., 22·7.

Uses.—A rare mineral, used as a source of iridium and platinum and their compounds.

Osmiridium (Iridosmine).—Native alloy of iridium and osmium. Iridium, 43 to 77 per cent.; osmium, 17 to 49 per cent.; platinum, trace to 3 per cent. In small flattened grains, sometimes hexagonal in outline, with basal cleavage. White or grey, metallic. Barely malleable, hard. G., 20. Found in sands associated with platinum, gold, etc.

Uses.—The chief source of iridium and osmium and their compounds.

5193.—Osmiridium, Clarence River, N.S.W.

Sperrylite.—Arsenide of platinum, $PtAs_2$. Platinum, 56 per cent. In small cubical crystals. White, metallic, brilliant, opaque. Brittle, hard. G., 10·6.

Occurs in veins, usually with copper ores, but occasionally with nickel and gold.

Uses.—A minor source of platinum and its compounds.

POTASSIUM.

This metal was first separated early in the 19th century, though some of its compounds, notably nitre, had been in use by man from time immemorial. It is a very soft, white, plastic, and sectile metal, which is rapidly oxidised by air or water, so that it has to be preserved under mineral oils. It is one of the lightest metals known, its specific gravity being less than one.

Potassium occurs as a constituent of very many rocks, especially granites, but cannot be profitably extracted from them or from any of the natural silicates, such as potash mica or felspar. The commercially most important minerals containing potassium are the

nitrate, nitre, or saltpetre; the chloride, sylvite; the double chloride with magnesium, carnallite; and the double sulphate and chloride, kainite.

Metallic potassium is not of commercial importance. Of the highest importance, however, are the nitrate and chlorate, used as constituents of various explosives, and the various soluble potash salts used as fertilisers. Potassium cyanide is largely used as a solvent for gold. Potassium chromate and bichromate are put to many uses (*see* p 26). Potash alum is a most useful salt, and is described under aluminium, page 12. Potassium hydrate, carbonate, ferrocyanide, iodide, bromide, etc., are put to various medicinal and other uses.

Nitre.—Nitrate of potassium, KNO_3. Potash, 46 per cent.; nitrogen pentoxide, 53 per cent. Crystallised, in thin crusts or powder. White, translucent. Very soft, brittle. G., 2·1. Occurs as an efflorescence on the soil in dry countries.

Uses.—After refining, is largely used in manufacturing gunpowder and other explosives. Also used as a fertiliser and in curing meat, etc.

Sylvite.—Chloride of potassium, KCl. Potassium, 52 per cent. (equal to potash 62 per cent.), but frequently intimately mixed with common salt. Crystallised, massive, granular, or compact. Colourless, white, or tinted. Transparent to translucent. Very soft, brittle. G., 2·0. Occurs in beds in sedimentary deposits.

Uses.—Used as a fertiliser and as a source of various salts of potassium, its value depending upon its purity and richness in potassium.

Carnallite.—*See* page 39.

Kainite (Kainit).—Hydrous chloride and sulphate of potassium and magnesium. Potassium 13 to 16 per cent. (equal to potash 16 to 20 per cent). Crystallised or granular, massive. Colourless, white, or tinted; translucent. Soft, brittle. G., 2·1. Occurs in sedimentary deposits.

Uses.—A very valuable fertiliser and source of potassium salts. Value depends on purity and richness in potassium.

SILVER.

Silver has been known to man for many centuries, being one of the few metals known to the ancients. It is white, and capable of a most brilliant polish, which undergoes no change in air or water unless sulphur be present, when it is blackened. In malleability and ductility it is second only to gold, than which it is slightly harder. It is the best known conductor of heat and electricity. Its specific gravity is 10·5, or between that of copper and lead.

Silver occurs native in a state of considerable purity and also occurs alloyed with gold. It also occurs in a vast number of compounds, comparatively few of which, however, constitute important

ores of the metal. Chief of these are the sulphide, argentite; the sulphides of silver, antimony, and arsenic, stephanite, pyrargyrite, proustite, and polybasite; the chloride, cerargyrite, and the chloro-bromide, embolite. Most lead ores, especially galena, contain more or less silver, also most copper ores, especially tetrahedrite (fahl-ore) and chalcocite. Blende, pyrites, and mispickel, also, at times, carry notable quantities of silver.

Metallic silver is largely used in the arts for preparing alloys and silver salts, and for plating various articles of utility and ornament. It is also used in assaying. The chief alloy is that with copper, which possesses all the beauty of the original silver, but is much harder. It is extensively used for coinage, tableware, jewellery, and innumerable articles of ornament, etc. The chief use for silver salts is in photography; the nitrate, bromide, chloride, and other compounds being used for this purpose. The nitrate is also used in analytical work, in medicine, and in the manufacture of marking inks.

Native ores of silver are used solely for the production of the metal, from which alloys or salts are subsequently obtained as desired. Their value depends upon the amount of the metal present and the ease with which it can be extracted. They occur in lodes and veins in crystalline and other rocks.

Silver (Native).—Silver, 70 to 99 per cent.; gold, trace to 30 per cent. Crystallised, dendritic, massive, or in scales. White, or tarnished grey or black, metallic, opaque. Malleable, soft. G., 10·5.

Uses.—*See* above. The gold present is occasionally of considerable value.

T. 24.—Native Silver, Spain.

Argentite.—Sulphide of silver, Ag_2S. Silver, 87 per cent. Crystallised or massive. Black, metallic, opaque. Very soft, sectile. G., 7·3.

Uses.—*See* above.

Stephanite.—Sulphide of silver and antimony. Silver, 68 per cent. Crystallised or massive. Black, metallic, opaque. Very soft, brittle. G., 6·2.

Uses.—*See* above.

Pyrargyrite (Dark Ruby Silver Ore).—Sulphide of silver and antimony. Silver, 58 to 61 per cent. Crystallised or compact, massive. Black or deep red, metallic, opaque except in thin splinters. Soft, brittle. G., 5·8.

Uses.—*See* above.

Proustite (Light Ruby Silver Ore).—Sulphide of silver and arsenic. Silver, 63 to 65 per cent. Crystallised or compact, massive. Red, brilliant, transparent to translucent. Very soft, brittle. G., 5·6.

Uses.—*See* above.

Polybasite.—Sulphide of silver, antimony, and copper. Silver, 62 to 72 per cent. Crystallised, metallic. Black and opaque, except in thin splinters, which are red to translucent. Soft, brittle. G., 6·1.

Uses.—*See* above.

Cerargyrite (Horn Silver).—Chloride of silver, AgCl. Silver, 75 per cent. Sometimes crystallised, usually massive, waxlike. White, greyish, or greenish, turns brown on exposure to the light. Transparent or translucent. Very soft and sectile. G., 5·5.

Uses.—*See* above.

T. 27.—Cerargyrite, Broken Hill, N.S.W.

Embolite.—Chloro-bromide of silver, Ag(ClBr). Silver, 61 to 72 per cent. Crystallised or massive. Green or yellow, darkening on exposure to light. Transparent to translucent. Very soft, sectile. G., 5·4.

Uses.—*See* above.

Argentiferous Galena, Tetrahedrite, and Blende, are important ores of silver, but when argentiferous have their usual appearance and characteristics. They are described elsewhere. (Galena, page 36, tetrahedrite, page 30, blende, page 61.) Many other minerals contain considerable percentage of silver, and if found in any quantity would constitute valuable sources of the metal. These minerals are of rare occurrence, and are described in text books of Mineralogy, *q.v.*

SODIUM.

Sodium, the metallic constituent of common salt, was first isolated and examined early in the 19th century. It is a soft, white, plastic metal, which is slightly lighter than water. It melts at a temperature below that of boiling water, and is one of the best known conductors of heat and electricity. It oxidises rapidly in moist air or in contact with water.

Sodium does not occur native, but is widely distributed in the form of various rock-forming silicates and as the chloride, common salt. This latter is the chief source of the metal and its salts. The nitrate, chili-nitre; sulphate, thenardite; and sesquicarbonate, trona, also occur native.

Metallic sodium is a most useful reducing agent, and is therefore used in the reduction of aluminium and other metals from their ores, as well as in the preparation of many organic compounds. Sodium amalgam, formed by dissolving sodium in mercury, is a good solvent for gold, and is largely used in gold amalgamation. A liquid alloy of sodium and potassium is used for high temperature thermometers.

The artificial compounds of sodium are manufactured on an enormous scale for many purposes. The peroxide is a most useful bleaching and general oxidising agent. Sodium chloride, both

crude and refined, is perhaps the most useful of all sodium compounds (*see* under Salt, *infra*). The carbonate, "soda," is mainly used in the manufacture of soap and glass, besides being put to a great number of other industrial and domestic purposes, such as the extraction of aluminium from its ores, the production of caustic soda, the refining of gold, and other metals, etc., in photography, analytical chemistry, etc. The bicarbonate is used as a source of carbonic acid for aerated waters, in cookery, in metallurgical processes, in scouring wool, etc. The hydrate, caustic soda, is used for the same purposes as the carbonate, as well as for the production of soluble glass, various organic dyes, and bleaching liquors, and for purifying crude oils, etc. The sulphate is used in the manufacture of many forms of glass; the thiosulphate in extracting silver from its ores, and in photography. Many other sodium salts are used for various industrial, medicinal, and other purposes.

Salt.—Chloride of sodium, $NaCl$. Sodium, 61 per cent.; chlorine, 39 per cent. Usually crystallised, also massive, compact, or granular. Colourless or tinted; transparent to translucent. Soft, brittle, G., 2·2. Occurs in stratified deposits or in beds of salt lakes. Also in solution, in large quantity, in sea water, and the water of many lakes and springs.

Uses.—Chiefly used, both crude and refined, as a food for men and animals, and as a source of soda and other sodium compounds. Also largely used as a source of chlorine and hydrochloric acid, as a preservative of meat, skins, etc.; as a glazing material for pottery-ware; in the metallurgy of gold and silver, etc. The value of the mineral depends upon its purity and freedom from admixed sand and compounds of lime, magnesium, and iron.

5365.—Crystallised Salt, Rottnest Island.

Chili Nitre.—Nitrate of sodium, $NaNO_3$. Soda, 36 per cent.; nitrogen pentoxide, 64 per cent. Sometimes crystallised, usually massive. White or tinted, transparent. Very soft, somewhat sectile. G., 2·3. Occurs in beds of dry lakes in desert regions.

Uses.—Chiefly used as a fertiliser and as a source of nitric acid, the percentage of nitrogen pentoxide governing its value for both purposes. Also used in the manufacture of nitre and sodium nitrate (for dyeing).

Trona.—Hydrous sesquicarbonate of sodium. Soda, 41 per cent.; carbon dioxide, 39 per cent. Crystallised or massive, fibrous or columnar. Grey or yellowish white, translucent. Soft, brittle. G., 2·1. Occurs in beds or crusts in the beds of dry lakes in desert countries.

Uses.—A source of sodium carbonate.

Borax.—Borate of sodium; *see* page 17.

STRONTIUM.

Strontium is a somewhat rare metal, which has been known for about a century. It is a soft, yellowish-white metal, of the same weight as aluminium. It is malleable, melts readily, oxidises rapidly in the air, and decomposes water with violence.

Strontium occurs in small quantities in most limestones and other mineral substances containing calcium. Its only ores are the carbonate (strontianite), and the sulphate (celestite).

The metal finds no application in the arts. The hydrate is used in the extraction of sugar from molasses, and the nitrate in pyrotechny as a constituent of all red fires.

Strontianite.—Carbonate of strontium, $SrCO_3$. Strontia (strontium oxide), 63 to 70 per cent. Crystallised, fibrous, or granular. Pale green, white, yellow; transparent to translucent. Soft, brittle. G., 3·7. Occurs in veins in granite or limestone.

Uses.—A source of strontium salts.

Celestite.—Sulphate of strontium, $SrSO_4$. Strontia, 50 to 56 per cent. Crystallised, fibrous, globular, or granular. White, pale blue, pale red; transparent to opaque. Soft, brittle. G., 4·0. Occurs in veins, etc., in limestone and sandstone.

Use.—A source of strontium salts.

SULPHUR.

Sulphur is one of the commonest of the non-metallic elements, and has been known from time immemorial. In its ordinary form it is a bright yellow crystalline substance, which melts readily and burns with the production of pungent fumes.

Sulphur occurs to a considerable extent in the free state in all volcanic districts. Its commonest compound is pyrites, sulphide of iron; whilst sulphides of lead, copper, and other metals are of frequent occurrence. Sulphates of lime and other metals are also common, but do not constitute a source of sulphur. Sulphur is also a constituent of coal and of animal and vegetable substances.

The most important use of sulphur is in the manufacture of sulphuric acid, but it is also largely used for making gun and blasting powder, sulphurous acid for vulcanising rubber, as an insecticide, for fumigating, and for the preparation of various sulphur compounds. By far the most important compound of sulphur is sulphuric acid, used in the manufacture of sodium carbonate (soda), hydrochloric, nitric, stearic, and other acids, alum, ether, nitro-glycerine, superphosphate, various metallic sulphates, etc. Sulphurous acid, metallic sulphites, and sulphates are used for a variety of purposes.

Sulphur (Native).—Pure sulphur mixed with various quantities of clay and other accidental impurities. Crystallised, massive, or earthy. Yellow, transparent to translucent. Very

soft, brittle. G., 2·0. Occurs in beds, veins, and irregular deposits in the vicinity of active or extinct volcanoes and hot springs.

Uses.—An important source of refined sulphur and sulphuric acid. Value depends upon its purity.

Pyrites.—Sulphide of iron, FeS_2. Sulphur, 53 per cent. Metallic, massive, or crystalline. Pale brass-yellow, opaque. Hard, brittle. G., 5·0.

Uses.—Largely used as a source of sulphur in sulphuric acid manufacture. For this purpose the ore should be free from arsenic, and should be dressed up to at least 45 per cent. Also used to a slight extent as a source of copperas (iron sulphate).

4294.—Pyrites, Crystals, Broad Arrow.
4039.—Pyrites, Northampton.
1103.—Pyrites, Coolgardie.

THALLIUM.

This very rare metal was discovered in 1861. It is bluish white in colour, soft and malleable, and melts below a red heat. It is slowly affected by air and water at ordinary temperatures. Its specific gravity is slightly higher than that of lead.

Thallium does not occur native, but is found in traces in certain samples of pyrites, and can be recovered from the flue dust when such samples are burnt for sulphuric acid manufacture. Thallium also occurs as the sulpharsenide, lorandite; and the selenide of copper, silver and thallium, crookesite.

Metallic thallium is not of any use in the arts, but the oxide is a constituent of certain varieties of optical glass, and the nitrate is used in examining gems, natural and artificial, and for certain other laboratory purposes.

Lorandite.—Sulpharsenide of thallium, $TlAsS_2$. Thallium, 59 per cent. Crystallised with a perfect cleavage. Red, often tarnished dark grey, metallic, brilliant, translucent. Soft, flexible. G., 5·5.

Uses.—A source of thallium salts.

Crookesite. — Selenide of copper, silver and thallium. Thallium, 16 to 19 per cent.; silver, two to five per cent. Massive, compact. Lead grey, metallic, opaque. Soft, brittle. G., 6·9.

Uses.—A source of thallium salts and silver.

THORIUM.

This rare metal was discovered in 1828. It is grey in colour, as heavy as lead, and not altered by the atmosphere, unless strongly heated, when it takes fire and burns.

Thorium occurs in nature in several rare silicates, titanates, and phosphates, of which the most important is monazite, which is

at present almost the sole source of thorium compounds. These minerals occur in crystalline rocks, especially granite and gneiss, and the heavy sands in rivers and on ocean beaches, resulting from their weathering. It is from these sands that almost all the commercial ore is obtained.

Metallic thorium has not, so far, been put to any use. Its most important compounds are the oxide and nitrate. The former, when mixed with a little oxide of cerium or zirconium, possesses in a marked degree the power of giving out an intense light when heated. For this reason it forms the chief constituent of Welsbach gas mantles and of the glower of the Nernst electric light. The nitrate is the salt which is used as a source of the oxide for these lamps.

Monazite.—Phosphate of cerium, lanthanum, and didymium $(CeLaDi)PO_4$, with variable amounts of thorium oxide from a trace up to 18 per cent., the average being $2\frac{1}{2}$ to $3\frac{1}{2}$ per cent. Crystalline or in water-worn grains, yellow or brown, semi-transparent, brittle, hard. G., 5·1.

Uses.—This mineral is the chief source of thorium salts, and its value is entirely dependent upon the percentage of that metal present. The sands containing the mineral are concentrated by hand or in hydraulic sluices, and if the resulting material does not contain 60 or 70 per cent. of monazite, it is still further concentrated by drying and removing all magnetite and titaniferous iron by an electro-magnet. For the market the dressed ore should contain 70 to 95 per cent. of the pure mineral.

5437.—Monazite Sand, North Carolina, U.S.A.

Thorite.—Silicate of thorium, $ThO_2.SiO_2$. Thorium oxide, 50 to 81 per cent. Crystallised or massive; yellow, brown, or black; semi-transparent, brittle, hard. G., 5.

Uses.—A source of thorium compounds, the value of the mineral depending on its thorium contents.

TIN.

Tin has been known for a great number of centuries, the Romans drawing supplies from Cornwall. It is a bright white metal which does not tarnish in the air. It is ductile, and very malleable. Its specific gravity is 7·2, or the same as zinc. It melts below a red heat.

Occasional grains of metallic tin have been found in various parts of the world, but they are very rare, and their origin is a matter of doubt. The chief ore of tin is the dioxide, cassiterite, or tinstone. Small amounts of the metal have also been obtained from stannite, a sulphide of tin, copper, and iron.

The chief use for metallic tin is as a coating to sheet iron, the so-called tin-plate, by which the surface of the iron is prevented from rusting or from contaminating articles of food, etc., stored or cooked in them. Pure tin, or block tin, as it is called, is used also

for various domestic and other appliances, such as still-worms, etc. Thin sheet tin, or tin-foil, is used in backing mirrors, wrapping up tobacco, soaps, sweetmeats, etc. Large quantities of tin are used in making various alloys, the most important of which are the following:—Solder and pewter (tin and lead); britannia metal (tin, lead, copper, and bismuth); gun metal (bell metal and some bronze, tin, and copper); other bronzes (tin, copper, and zinc or lead); phosphor-bronze (tin, copper, and phosphorus); fusible metal (lead, tin, bismuth, etc.).

Several compounds of tin are largely used in dyeing and calico-printing; viz., stannous chloride, stannic chloride, stannic-ammonium chloride, and sodium stannate. The artificial dioxide (putty powder) is largely used for polishing metals, glass, stones, and gems, and as a constituent of enamels. Stannic sulphide, or mosaic gold, was at one time used as a substitute for gold-leaf.

Cassiterite (Tinstone).—Oxide of tin, SnO_2. Tin, 68 to 78 per. cent. Crystallised, massive, or in rolled grains. Brown, black, red, or grey; translucent to opaque. Hard, brittle. G., 7·0.

Occurs in veins or altered bands in granite, or in veins in sedimentary rocks close to their contact with granite; also largely in alluvial deposits derived from their denudation.

Uses.—The main source of tin and its compounds. The value of tin ores depend upon their richness in tin, and upon the nature and amount of associated minerals. For smelting, tin ores should be dressed up to at least 55 per cent. metal, as, otherwise, a large loss is experienced in smelting. Where the tinstone is accompanied by wolfram, tantalite, stibiotantalite, or other minerals of the same or higher specific gravity, the ordinary methods of water concentration are unable to remove these impurities, and the concentrated ore is consequently low in grade and loses greatly in value. Such constituents are, therefore, a considerable drawback to the ore. Stibiotantalite is also very objectionable, because it introduces antimony into the smelted tin. The most valuable tin ores are those entirely free from all other metallic minerals.

2026.—Cassiterite (stream tin), Coglegong Creek, Pilbarra Goldfield

1287.—Cassiterite (stream tin), Greenbushes. Low-grade ore with much tantalite and stibiotantalite.

1999.—Cassiterite in greisen, Greenbushes.

5397.—Cassiterite in albite vein, Moolyella, Pilbarra Goldfield.

Stannite (Tin Pyrites).—Sulphide of tin, copper, iron, and zinc. Tin, 23 to 27 per cent.; copper, 29 per cent. Massive or granular. Metallic, black or dark grey, opaque. Soft, brittle. G., 4·4. Occurs in veins in granite or slate.

Uses.—A very rare source of tin and its compounds. The copper present adds to the value of the mineral.

T. 19.—Stannite, Cornwall, England.

TITANIUM.

This metal in small quantities is very widely distributed, being found in all igneous rocks and many sedimentary ones. It was first discovered at the end of the eighteenth century, and in its purest form is a dark grey powder, lighter than iron, which burns brightly on being heated in the air. It dissolves readily in dilute acids.

Titanium never occurs native. Its most common compound is ilmenite, the titanate of iron, which occurs as a constituent of many rocks, and is often found as "black sand" along rivers and sea coasts. The only other mineral which constitutes a source of titanium is the oxide, rutile.

Metallic titanium is not used in the arts, but alloys with iron, known as ferrotitanium, are at times added to cast iron and steel, with the effect of increasing their strength and hardness. Titanium oxide is used in porcelain painting, and enters into the composition of artificial teeth.

Ilmenite.—*See* page 35.

Rutile.—Oxide of titanium, TiO_2. Titanium oxide, 90 to 100 per cent.; titanium, 54 to 60 per cent. Crystallised or compact, massive. Brown, red, yellow, occasionally other tints; transparent to opaque. Hard, brittle. G., 4·2.

Uses.—A source of titanium alloys and compounds. When very pure, used for same purposes as artificial titanium oxide.

T. 111.—Rutile, Norway.
1919.—Rutile, Greenbushes.

TUNGSTEN.

This metal was discovered in 1782. It is as heavy as gold, but of grey colour, and is practically unaffected by the atmosphere. In its pure form the metal has no application in the arts.

Metallic tungsten does not occur in nature, its chief ores being the tungstate of iron, manganese, and lime, compounds of oxide of tungsten with oxides of those metals. These ores usually occur in quartz veins in granite, greenstone, or slate, and are principally mined in the United States, Austria-Hungary, Spain, and Queensland. They are known to occur in this State at Kalgoorlie, Coolgardie, Southern Cross, the ranges near Geraldton, and in the Pilbara district.

The chief use of tungsten is in hardening steel, for which purpose it is put on the market either as the impure metal or as ferrotungsten, an alloy of iron and tungsten obtained by smelting wolfram. Tungsten-steel, containing from 2 to 12 per cent. of the metal, is largely employed for guns and machine-tools, and to a less extent for rails. Nearly all the Sheffield crucible-steel makers are said to make use of it to a slight extent. The German Government has also tried it in bullet-making, as a small percentage of tungsten, added to lead, renders it harder and increases its penetrating power, without raising its melting point.

The only compound of tungsten which is used in the arts is sodium tungstate, a white crystalline salt used as a mordant and for saturating inflammable materials to render them non-inflammable, also for hardening plaster of Paris.

Wolfram or Wolframite.—Tungstate or iron and maganese, $(FeMn)WO_4$. Tungsten, 60 per cent.; tungstic oxide, 76 per cent.; massive or crystallised. Somewhat hard, black or dark brown, opaque, brilliant lustre, well marked cleavage. G., 7·4.

Uses.—Used solely as a source of tungsten, ferro-tungsten, and sodium tungstate. Its commercial value depends almost entirely upon the percentage of tungstic oxide present, but, other things being equal, an ore containing traces only of phosphorus and sulphur is worth more than one containing appreciable quantities of those substances. Ores containing wolfram are readily concentrated by hand or by machinery, and for export such concentrates should assay not less than 50 per cent. of tungstic oxide. Ore over 55 per cent. is worth considerably more per unit than ore under that grade. Any admixture of tin ore lowers the value of the product.

614.—Wolfram, Roebourne.
4356.—Wolfram, Herberton, Qld.

Huebnerite.—Tungstate of manganese, $MnWO_4$. Tungsten, 60 per cent.; tungstic oxide, 76 per cent. Similar in appearance and properties to wolfram.

Uses.—*See* Wolfram.

Scheelite.—Tungstate of lime, $CaWO_4$. Tungsten, 64 per cent.; tungstic oxide, 80 per cent.; massive or crystallised. White or slightly tinted yellow, etc., brilliant lustre. Hard, brittle. G., 6·0.

Uses, etc.—*See* remarks under Wolfram.

1299.—Scheelite, Coolgardie. Massive yellow, with a considerable amount of impurity.

1414.—Scheelite, Southern Cross. Clean, yellow, massive, in quartz vein.

1358.—Scheelite, Hillgrove, N.S.W. Clean, white, massive.

[The following extract from a report by Mr. C. F. V. Jackson, Assistant Geologist, gives some further particulars in connection with the uses and values of wolfram ores:—

Tungsten ores are frequently found associated with tin and in staniferous leads, and considerable supplies have been derived from tin workings and by working over the waste from old tin-dressing floors. In addition to such deposits as are included above, wolfram occurs in veins and small bunches in crystalline and metamorphic rocks generally associated with a gangue of quartz. In North Queensland, the principal source of the mineral in Australia, the majority of the wolfram-producing claims lie along a fairly continuous reef of quartz, the granite for some distance on either side being intersected by an irregular system of smaller quartz veins and offshoots, from which the wolfram is chiefly obtained. The output of the Queensland fields from 1894 to the end of 1903 was estimated at 947½ tons. New South Wales, South Australia, Tasmania, and New Zealand have pro-

duced small quantities, but the output has generally been only indirectly recorded or stated under the head of sundry minerals, and for this reason also the world's statistics are not immediately available. The tungsten combined in wolfram is generally estimated as tungstic acid, the pure mineral (tungstate of iron and manganese) containing from 73 to 76 per cent. of tungstic acid. The commercial ore, owing to the admixture of quartz and other impurities, rarely contains over 70 per cent., but should be dressed to contain not less than 60 per cent., the price for the ore being based on the ruling rate for 60 per cent., plus an additional sum for every unit of tungstic acid above 60.

Until recent years, about the only uses of tungsten were in the preparation of the salts of the metal for various technical purposes; its chief use now is either in the form of the alloy, ferro-tungsten, or as the powdered metal, in the manufacture of tungsten steel. Alloys are also made of tungsten with aluminium and copper, the latter being used in the manufacture of propeller blades. Ferro-tungsten, the alloy of tungsten, is easily prepared from wolfram and scheelite by direct reduction with iron or ferric oxide. Tungsten, when added to steel in small proportions, renders it particularly hard, and also self-tempering. Tungsten steel is therefore used in the manufacture of tool steel and wearing parts of machinery, but particularly for heavy guns and battleships' armour, Germany, in consequence, being one of the best markets for tungsten. Some three years ago it was estimated that about 75 tons of tungsten were used annually at the Krupp works in the manufacture of guns, etc., the market value of tungsten being comparatively low. During the last three years there has been a great rise in the price, and wolfram has gone from £30 per ton to £130 or £140 per ton for ore containing 60 per cent. of tungstic acid. A note in *L' Echo des Mines et de la Metallurgie* states that "the price of ferro-tungsten in France last October was, for alloy containing 80 per cent. of tungsten, 4fr. (3s. 2d.) per unit. In December it had advanced to 5fr. (4s. 9d.), and is now 6fr. (5s. 6½d.) per unit, with no chance of getting prompt delivery." This advance in price is attributed to deposits of tungsten minerals being scarce, of limited extent, and little developed; while the demand has developed so suddenly during the present year that there is no prospect of meeting it immediately. At the middle of last year wolfram was selling on the fields in North Queensland at £29 per ton, and at the end of 1903 it was £50, since when it had risen to over £120. It is there chiefly purchased by agents, who visit the field for the purpose. In this connection, however, while the general statement that wolfram in August last was worth £130 to £140 per ton might be accepted as indicating the market conditions existing, the fact is not to be lost sight of that the demand for wolfram is, comparatively speaking, small and somewhat irregular, tungsten only being used in small proportion for steel suited to a few purposes. Moreover, there is hardly reasonable ground or reliable data for assuming that the market is sufficiently stable to render mining for wolfram, except where it may be obtained as a bye-product, more than a highly speculative business, since the prices are liable to rise and fall considerably, and whilst the mineral might go up to £200, there is no sufficient guarantee that more abundant supplies and an increase of production will not suddenly put it back to £30.]

URANIUM AND RADIUM.

These two rare metals occur together in nature in the same minerals, and will therefore conveniently be dealt with together.

Uranium compounds were known and recognised as early as 1789, but it was not till 1842 that the metal was isolated. It resembles nickel in appearance, is malleable, and hard and as heavy as gold. It tarnishes readily in the air, and in the form of powder

takes fire at a temperature below the melting point of tin. Both the metal and its compounds are radio-active, that is, give out energy spontaneously and continuously.

Radium, the newest and most wonderful of all the metallic elements, is only known in combination with other elements, the metal itself not having yet been separated. The most interesting and valuable property of radium salts, and probably also of the metal, is their extreme radio-activity, which is something like a million times as great as that of uranium.

The chief ores of uranium are uraninite (pitch-blende), a complicated compound containing uranium, lead, thorium, etc.; torbernite, phosphate of uranium and copper; autunite, phosphate of uranium and lime; and carnotite, vanadate of uranium and potassium. All these appear to carry minute amounts of radium, varying from one-tenmillioneth to one-millioneth part of the whole. These ores occur principally in quartz veins and as impregnations in sandstone, sometimes also in pegmatite veins.

Metallic uranium is only of scientific interest; a little of it added to steel in the form of uranium carbide is said, however, to improve it for many purposes. The acetate and nitrate are used for analytical work and in photography. Uranium compounds are also used in enamel painting and for staining glass, uranous oxide giving a fine velvety black colour and uranic oxide a delicate greenish-yellow highly fluorescent glass, which, besides being ornamental, possesses also the property of arresting chemically active rays.

The most important radium salts are the chloride and bromide, which are being largely experimented with for various purposes.

Uraninite (Pitch-blende).—Uranate of uranium, lead thorium, etc. Uranium, 50 to 75 per cent.; radium, trace. Usually massive botryoidal, sometimes crystallised or granular. Grey, green, brown, or black, with lustre varying from submetallic to greasy or dull. Opaque, brittle, hard. G., 7 to 9·5.

Uses.—Used solely as a source of uranium and radium, its value depending on the proportion of these metals present. The relative proportion of radium present may be roughly gauged by the radio-activity of the mineral. That from Johanngeorgenstadt, in Saxony, and Joachimsthal, in Bohemia, gives the highest results.

T. 126.—Uraninite, Cornwall, England.

Torbernite (Copper Uranite).—Hydrous phosphate of uranium and copper. Uranium, 45 to 50 per cent.; radium, trace. Scaly massive or in micaceous crystals. Green, transparent or translucent. Brittle, very soft. G., 3·5.

Uses.—Constitutes a source of uranium and its salts. Radium has been detected in some specimens, though in much smaller amount than in uraninite.

T. 127.—Crystallised Torbernite, Cornwall, England.

Autunite (Lime Uranite).—Hydrous phosphate of uranium and calcium. Uranium, 44 to 50 per cent.; radium, trace. Scaly massive or in micaceous crystals. Yellow, transparent or translucent. Brittle, very soft. G., 3·1.

Uses.—*See* Torbernite.

T. 129.—Crystallised Autunite, Cornwall, England.

Carnotite.—*See* under Vanadium, *infra.*

VANADIUM.

Until quite recently vanadium, which was discovered in 1801, was thought to be a very rare metal, and, like all such, commanded a price altogether out of proportion to its usefulness in the arts. It is now known to be widely distributed over the globe in minute quantities.

Vanadium is a very infusible metal which is but little affected by the air at ordinary temperatures, or by contact with many mineral acids. It is grey in colour, and has a specific gravity about one-half that of silver.

Vanadium occurs commonly in small proportions in most iron ores (especially titaniferous magnetites) and volcanic rocks, as well as in many coals, clays, sandstones, and limestones. The clay beds in the vicinity of Sydney are vanadium-bearing, the metal showing its presence by a yellowish-green colouration on the weathered surfaces of bricks made from it. In spite of this wide distribution of the metal in traces, ores of it (*i.e.*, deposits of minerals carrying a notable percentage of the metal) are very rare. The most important of these are carnotite, a vanadate of uranium and potash occurring in Colorado; roscoelite, a silicate of potash aluminium and vanadium, which has been detected at Kalgoorlie; and vanadinite, a vanadate and chloride of lead, small crystals of which have been found in several gold reefs in Western Australia. One of the chief sources of vanadium at present is the iron slags from the Creusot Works in France, where vanadium-bearing iron ores are smelted.

The pure metal is not used for any but experimental purposes. An alloy of vanadium and iron, ferro-vanadium, is added to steel to improve its qualities for many purposes. Steel thus prepared is eminently suited for armour plate, projectiles and machine tools, since not only is it extremely tough and hard but it does not lose this hardness by being heated to a bright red heat and slowly cooled. Vanadic acid is largely used for the production of indelible black dyes and inks. Various pigments used in colouring porcelain and glass also contain vanadic acid.

Carnotite.—Hydrous vanadate of potassium and uranium. Vanadium, 11 per cent.; vanadium pentoxide, 20 per cent. Occurs

in yellow disseminated grains and bunches in sandstone in Colorado, the rocks being leached with nitric acid to obtain the vanadium.

Uses.—One of the chief sources of vanadium and uranium and their salts.

Roscoelite.—Silicate of potassium, vanadium, and aluminium. Vanadium, 15 per cent.; vanadium pentoxide, 28 per cent. In mica-like scales, brown or brownish green. Translucent, soft. G., 2·9.

Uses.—Used as a source of vanadium compounds.

Vanadinite.—Vanadate and chloride of lead. Vanadium, 4 to 11 per cent.; vanadium pentoxide, 8 to 20 per cent. In red or yellow crystals or incrustations. Brittle, soft, opaque. G., 6·8.

Uses.—Used as a source of vanadium compounds, and of metallic lead.

T. 82.—Vanadinite, New Mexico, U.S.A.

ZINC.

Zinc, or spelter, is a common metal which has been known to civilised man for several centuries. It is a blueish white crystalline metal, brittle at ordinary temperature, but malleable and ductile at a little above the temperature of boiling water. It takes a good polish and is unaffected by perfectly dry air, but is rapidly coated in moist air with a greyish white tarnish, which protects the metal from further corrosion. It is readily soluble in dilute acids, and has a specific gravity of 7·1.

Native zinc has been reported to occur in very small quantities, but its occurrence needs confirmation. The sulphide, blende, is a common constituent of veins, whilst the oxide zinkite; the carbonate, smithsonite and hydrozinkite, and the silicates, willemite and hemimorphite are less common ores. Franklinite, an oxide of iron and zinc, occurs plentifully in New Jersey, U.S.A.

Metallic zinc is chiefly used for roofing purposes, either in sheets or as a surface coating upon iron, which is then said to be galvanised. Sheet zinc is also used for various internal ornamental work, lining packing cases, making water tanks and pipes, etc. In plates it is used to prevent corrosion of boilers, also in galvanic batteries, in photo-engraving, etc. Fine shavings of zinc are used to precipitate gold from cyanide solutions; whilst zinc powder is used as a reducing agent in manufacturing organic compounds, as a paint, and in the preparation of zinc salts. Spelter is used for making castings, for desilverising lead, for coating iron and steel, and for making alloys.

Of metallic alloys the most important are brass and bronze, in the preparation of which large quantities of zinc are consumed. Zinc also forms useful alloys with alluminium and with nickel and copper.

Oxide of zinc (zinc white), obtained from the metal or direct from the ore, is a very valuable pigment which has largely replaced

white lead. It is also used as a constituent of many rubber goods. Zinc chloride is used as a disinfectant, and preservative of wood, in refining oils, and in making stearic acid, ether, and parchment paper. Zinc sulphate is used in dyeing, in the manufacture of glue, and the pigment known as lithophone, and as a dryer in oil paints and varnishes. Zinc chromate is used as a pigment. Several zinc salts are used in medicine.

Blende (Sphalerite).—Sulphide of zinc, ZnS. Zinc, 57 to 67 per cent. Crystallised or massive cleavable, granular to compact. Yellow, brown, black; transparent to opaque. Soft, brittle. G. 4·0. Occurs in veins in crystalline and other rocks, also in irregular masses and veins in limestone.

Uses.—The commonest source of zinc and its compounds. Value of this and other zinc ores depends upon percentage of zinc present, and on freedom from lead ores. Ores or concentrates containing over 4 per cent. of lead are practically unsaleable to smelters.

T. 86.—Crystallised Blende, Cumberland, England.

4032.—Massive Blende, Northampton.

Franklinite.—*See* page 35.

Zinkite.—Oxide of zinc, ZnO. Zinc, 74 to 80 per cent. Rarely crystallised, usually massive granular or foliated. Deep red to orange, translucent. Soft, brittle. G., 5·6.

Uses.—A source of zinc. *See* remarks under Blende.

T. 90.—Zinkite, New Jersey, U.S.A.

Smithsonite.—Carbonate of zinc, $ZnCO_3$. Zinc, 42 to 52 per cent. Crystallised or massive granular or earthy, also stalactitic. White or tinted, translucent. Hard, brittle. G., 4·4. Occurs usually in veins and irregular masses in limestones.

Uses.—*See* Blende.

4351.—Smithsonite, Chillagoe, Qld.

Hydrozinkite.—Hydrous carbonate of zinc. Zinc, 55 to 60 per cent. Massive, compact, fibrous, earthy, or stalactitic. White, grey, or yellow; opaque, dull. Soft, brittle. G., 3·7.

Uses.—*See* Blende.

Willemite.—Silicate of zinc, Zn_2SiO_4. Zinc, 48 to 58 per cent. Crystallised, massive, compact, or fibrous. White or tinted, transparent to opaque. Hard, brittle. G., 4·0.

Uses.—*See* Blende

T. 94.—Willemite, New Jersey, U.S.A.

Hemimorphite.—Hydrous silicate of zinc. Zinc, 50 to 54 per cent. Crystallised, stalactitic, fibrous, massive, granular. White or tinted, transparent to translucent. Hard, brittle. G., 3·5.

Uses.—*See* Blende.

T. 93.—Hemimorphite, Laurium, Greece.

ZIRCONIUM.

This rare element was discovered at the close of the 18th century. It is a crystalline metal resembling antimony in appearance and oxidising but slowly in the air. It is soluble in warm acids and has a specific gravity of 4·1.

Zirconium does not occur free in nature; its commonest compound is the silicate, zircon, which occurs in small quantities in granite and other crystalline rocks, and in the sands resulting from their denudation. Zirconium also occurs in several rare silicates, tantalates, etc.

The metal is not applied to any useful purpose, but the oxide (zirconia) is employed in the glowers of Nernst and other lamps, having the property of yielding an intense light at comparatively low temperatures.

Zircon.—Silicate of zirconium, $ZrSiO_4$. Zirconia, 61 to 67 per cent. Usually crystallised, also in rolled grains. Colourless or tinted, transparent to opaque. Very hard, brittle. G., 4·7.

Uses.—Used as a source of zirconia. Some varieties used as a gem, *see* page 68.

5549.—Zircon Sand, Donnelly River.

SILICA AND SILICATES.

Silica, the oxide of the nonmetallic element silicon, is widely and abundantly distributed in the form of quartz (free silica) and various silicates of the metals. It is a colourless, transparent, crystallised substance, which is very hard and infusible and resists the action of most acids.

By far the most important artificial substance containing silica is glass, which is a silicate of sodium and calcium or other metallic base. Hydraulic cement is a silicate and aluminate of calcium. Carborundum, a valuable abrasive, is a carbide of silicon.

Quartz.—Silica, SiO_2, with more or less admixed oxide of iron, etc. Crystallised or massive, compact or granular. Coluorless, white or tinted; transparent to opaque. Hard, brittle to tough. G., 2·6.

Uses.—Largely used as a refractory material and in the manufacture of glass and porcelain. For these purposes and for making carborundum it should be very pure and especially free from iron compounds. Less pure varieties are used as an abrasive, for making mortar, for filters and for a multitude of other purposes. Perfectly transparent, flawless crystals, or masses are used for making lenses and ornaments and are of considerable value.

4669.—Quartz Crystal, Hardy River.

4360.—Pure Quartz Sand, Lake Gnangara.

Diatomaceous Earth (Infusorial Earth).—Hydrous silica with more or less admixed organic matter, clay, etc. Consists of the accumulated remains of minute water plants. Massive, tough, or earthy and friable. White, grey, or black; opaque. Very soft and porous. G., 1·2 in bulk and dry, 0·2 up to 0·8. Occurs in surface or buried beds. Often occurs in beds of lakes and swamps.

Uses.—When calcined artifically or by nature so as to remove all organic matter and moisture, is used for a great variety of purposes. It is largely employed as an abrasive, especially as a constituent of polishing powders and soaps, for this purpose it should be as free as possible from admixed sand or grit. Owing to its great porosity it is largely used as an absorbent, especially for nitro-glycerine forming dynamite; for disinfectants, etc. Its utility for these purposes depends upon its absorbent capacity, and in the case of dynamite, upon the presence of many closed spaces in the individual diatom skeletons, and its practical freedom from alumina or lime. Its porosity, lightness, infusibility, and low conductivity for heat make it a valuable heat insulator for refrigerating chambers and wagons, for safes, boiler and steam-pipe coverings, "refrigerating" paints; and as a constituent of fire-resisting cements and bricks. The purest varieties are used also for making soluble glass and other glasses; and as an adulterant of rubber. For most purposes diatomaceous earth should be as free as possible from alumina, lime, iron oxide, and alkalies; and should be highly porous and absorbent.

4361.—Crude wet Diatomaceous Earth, Lake Gnangara.
4365.—Calcined Diatomaceous Earth, Lake Gnangara.
4468.—Crude Diatomaceous Earth, Little Badgerup Lake.
5052.—Crude Diatomaceous Earth, Cooma, N.S.W.

Asbestos.—This is a name applied both in commerce and science to several silicates characterised by a finely fibrous structure. The chief varieties are Amianthus, Chrysotile, Picrolite, and Actinolite.

Amianthus.—Hydrous silicate of magnesia. In long, fine, silky fibres, very flexible and tough. White or pale green, opaque. Occurs in veins and pockets in serpentine.

Uses.—This is the most valuable variety of asbestos owing to the length, evenness, flexibility and toughness of the fibres, the ease with which they can be separated from one another, and their great resistance to heat and poor conductivity. It is woven into packing for pistons, valves, and other parts of engines; into rope for suspending crucibles, etc., in contact with fire, and for use in theatres and acid works; into cloth for theatre screens, colliery doors, etc. The scrap is used for the same purpose as chrysotile and picrolite.

Chrysotile.—Hydrous silicate of magnesia. In short ($\frac{1}{4}$ inch to 4 inch) soft fibres, very flexible and tough. Pale green, opaque. Occurs in veins in serpentine.

Uses.—This forms the great bulk of the world's asbestos. It is woven into yarn and cloth for packings, etc. Also made into felt for fireproof screens, etc. Used also for covering steampipes, etc., for lining for safes and many other purposes. Less valuable than Amianthus.

1010.—Asbestos, var. Chrysotile, near Tambourah.

1821.—Asbestos, var. Chrysotile, Metford, Canada.

Picrolite.—Hydrous silicate of magnesia. In short or long irregular fibres, very soft and brittle and of low tensile strength. Pale green, opaque. Occurs in veins in serpentine.

Uses.—This is one of the commonest but least valuable varieties of asbestos. It cannot be woven but is used as a base for heat-proof paints and cements, boiler coverings, etc.

5517.—Asbestos, var. Picrolite, Pickering Brook.

Actinolite.—Silicate of calcium, magnesium, and iron. In short or long irregular fibres, hard, brittle, and very difficult to separate. White or pale green, opaque. Occurs in veins and nests in basic igneous rocks.

Uses.—Of little value but can be used for same purposes as Picrolite.

1098.—Asbestos, var. Actinolite, Ballagundi.

The market value of asbestos depends upon the length, strength, evenness, infusibility, and flexibility of the fibres, and the ease with which they can be separated from one another, and also upon its freedom from admixed rock, iron oxide, etc. Fresh uses are continuously being found for asbestos, but so far the supply has been so well kept up that the price of the mineral has decreased considerably within recent years. Before marketing, asbestos is graded according to length into long, over $\frac{3}{4}$inch; medium, $\frac{1}{2}$ to $\frac{3}{4}$inch; short, under $\frac{1}{2}$inch.

Mica.—Like asbestos, this name is applied both commercially and scientifically to several distinct silicate minerals, all of which are characterised by a very perfect cleavage which enables them to be split into thin elastic plates. The most important species are Muscovite, Phlogopite, Biotite, and Lepidolite.

Muscovite.—Common or white mica. Silicate of aluminium, potassium, and hydrogen. Crystallised or foliated massive. Colourless or tinted; transparent. Soft. G., 2·8. Laminæ flexible, elastic, tough, and very infusible. Occurs in pockets or veins in granite or gneiss, especially in pegmatite veins.

Uses.—This is the most useful variety of mica. In sheets at least 2 inches x $1\frac{1}{2}$ inch, is used for windows of stoves and furnaces, for funnels for lamps and gaslights, for skylights and compass-covers. Large quantities of sheet mica are used for electrical insulations. The scrap mica left after trimming the mineral into sheets is used for a variety of purposes. It is cemented into sheets and used for electrical insulation, under the name of "micanite."

When ground, it is used as a lubricant, as a constituent of some brands of dynamite, of various piston packings, fire-resisting paints, and insulating compounds, in the manufacture of lustrous hair powder, and mixed with plaster of Paris for moulds for castings. It is also used to a certain extent in decorative work, both in sheets and powder. An excellent non-conducting covering, which is both flexible and fireproof, is formed by a quilting finely powdered scrap between galvanised wire netting.

5188.—Mica, var. Muscovite, Macdonnell Range, S.A.

Phlogopite.—Amber mica. Fluo-silicate of aluminium, magnesium, and potassium. Crystallised or foliated massive. Usually amber, sometimes colourless or tinted variously; transparent to translucent. Soft. G., 2·8. Laminæ flexible, elastic, tough, and infusible. Occurs in veins or pockets in serpentine, crystalline limestone, or dolomite.

Uses.—*See* Muscovite.

Biotite.—Black mica. Silicate of aluminium, magnesium, iron and potassium. Crystallised or laminated massive. Black, green, yellow, or brown; transparent to opaque. Soft. G., 2·8. Laminæ flexible, elastic, tough, and infusible. Occurs in veins and pockets in granite and other crystalline rocks.

Uses.—Owing to low electric resistance, is not of much value for insulating purposes. Used for most other purposes described under Muscovite.

Lepidolite.—Lithia mica. Fluo-silicate of aluminium, potassium and lithium. *See* page 37.

Uses.—Owing to easy fusibility, cannot be used for any of the purposes to which other micas are put, except the ornamental purposes. Chiefly used as a source of lithium salts.

556.—Mica, var. Lepidolite, Londonderry.

777.—Mica, var. Lepidolite, trimmed for market, Londonderry.

Mica is marketed in two forms, viz., "sheet," consisting of thin rectangular blocks of certain standard sizes, varying from 2 inches by $1\frac{1}{2}$ inches up to 8 inches by 10 inches or more; and "scrap," the small pieces left after punching out the sheets from the crude mineral. The latter is of very little value, something like 1d. to 2d. a pound. The value of sheet mica depends upon the size of the sheet (varying from 3s. per lb. to £2 10s. per lb.), the ease with which it can be split up, its softness, flexibility, and freedom from wrinkles and blemishes. When used as a substitute for glass its transparency and colour are important points. For electrical purposes its resistance to heat and electricity are of importance.

Talc (Steatite, Soapstone).—Hydrous silicate of magnesium. Rarely in tabular crystals, usually massive, foliated, granular, compact, or fibrous. White or green; translucent. Very soft, sectile. G., 2·7. Occurs as rock masses and in veins and beds.

Uses.—When powdered, is largely used as a filling for paper; for this purpose the fibrous form is the best. Also for fire-proof paints, electric insulators, steam-pipe and boiler coverings, foundry facings, toilet powders, lubricants, and as a base for dynamite and cheap soap. Compact talc is cut into pencils, fire-bricks, hearth-stones, footwarmers, etc.

4294.—Fibrous and massive talc, Broad Arrow.

Feldspar.—This name is applied to a group of minerals closely related to one another in occurrence, properties, and composition; being silicates of aluminium with potassium, sodium, or calcium. The chief varieties from a commercial point of view are orthoclase and albite.

Orthoclase.—Silicate of aluminium and potassium. Crystallised with a perfect cleavage or massive. Colourless, white, or tinted; transparent to opaque. Hard; brittle. Occurs in workable deposits chiefly in pegmatite veins.

Uses.—Chiefly used as a constituent of china, porcelain, tiles, and certain varieties of glass. Also used as an abrasive especially in polishing-soaps. Small quantities used in dentistry. Has been proposed to utilise it as a source of potash salts.

378.—Feldspar, var. Orthoclase, Londonderry.
24.—Feldspar, var. Orthoclase, Northampton.

Albite.—Silicate of aluminium and sodium. Crystallised with perfect cleavage, massive granular or lamellar. White or tinted; transparent to opaque. Hard; brittle. Occurs in workable deposits chiefly in pegmatite veins.

Uses.—*See* Orthoclase.

5288.—Feldspar, var. Albite, Ravensthorpe.
5397.—Feldspar, var. Albite, with tin ore, Moolyella.

Other varieties of feldspar could be utilised for a similar purpose were workable deposits of them available. For market the ore must be carefully hand-picked to remove all associated minerals especially those containing iron. Feldspar containing more than a trace of iron is not suited for making porcelain or glass. A small unavoidable admixture of clean, colourless quartz is no great drawback to the mineral.

Garnet.—This group of minerals is characterised by a similarity of crystalline form, chemical composition, and occurrence. The commonest species are almandite and andradite.

Almandite.—Silicate of ferrous iron and aluminium. Crystallised, massive, granular, or compact. Red or black; transparent to opaque. Hard, brittle, or tough. G., 4·0. Occurs in granite or other rocks, or in beach or river sands.

Uses.—Used largely as an abrasive. Fine clear specimens make gems. *See* page 69.

4797.—Garnet in granite, Upper Bowes River.
5315.—Garnet, near Marble Bar.
4794.—Garnet sand, mouth of Bowes River.

Andradite.—Silicate of calcium and ferric iron. Crystallised, massive, granular, or compact. Black, green, yellow, brown; transparent to opaque. Hard, brittle, or tough. G., 3·9. Occurrence and uses same as for almandite.

The value of garnet as an abrasive depends upon its hardness and toughness, and its freedom from mechanically admixed impurities. Other varieties of garnet, if found in workable quantities, could be used for the same purpose as almandite and andradite.

GEMS AND ORNAMENTAL STONES.

Gems, which include the most valuable of all minerals, may be defined as those varieties of mineral species which possess such striking and permanent beauty as to make them desirable articles of personal adornment. The value of gems depends upon their freedom from flaws or blemishes, the shade of colour they possess, and the permanency of that colour when exposed for long periods to light and air; their degree of transparency (except in the case of perfectly opaque gems such as turquoise); their hardness, and finally their rarity. The following is the approximate order of value of precious stones:—Pearl, Ruby, Diamond, Emerald, Sapphire, Oriental Cat's Eye, Opal, Turquoise, Alexandrite.* Other ornamental stones, such as Tourmaline and Jade, are classified as "semi-precious," owing to their inferior rarity and value. In the following pages the order followed under the headings of "Precious Stones" and "Semi-precious Stones" has been determined by the chemical and mineral nature of the gems. In each case the general description given is that of the most valued type, and is in more detail than those of less valuable minerals given in this brochure.

Precious Stones.

Diamond.—Pure carbon, C. Crystallised in octahedra and other forms of the isometric system; also in water worn pebbles. Transparent. Most valuable are colourless, red, or blue; of less value those that are yellow, green, or brown. Hardness, 10; G., 3·5. Occurs in basic igneous rocks and in alluvial deposits. At the present day South Africa supplies the greatest part of the total demand for this gem. Small diamonds have been found in conglomerate at Nullagine, in this State.

Ruby.—Variety of Corundum. Oxide of aluminium, Al_2O_3. Crystallised in hexagonal pyramids, more or less modified; also in water-worn pebbles. Transparent. Pigeon-blood red; less valued gems are of other shades of red. H., 9.; G., 4·0. Occurs in Crystalline limestone and in alluvial deposits. Chiefly derived from Burmah.

Sapphire.—Variety of Corundum. Oxide of aluminium, Al_2O_3. Form and other characters, except colour, as for Ruby. Colour, corn-flower blue or rarely rich green; other shades of blue are less admired. Occurs in crystalline limestone, basic igneous rocks, and mica-schist, also in alluvial deposits. The chief sources of sapphires are Siam, Burmah, Cashmere, and Ceylon.

Sapphires and other gem stones, Inverell, N.S.W.

* E. W. Streeter, Precious Stones and Gems.

Emerald.—Variety of Beryl. Silicate of beryllium and aluminium, $3BeO.Al_2O_3.6SiO_2$. Crystallised in hexagonal prisms. Transparent; rich green in colour. H., 7·5. G., 2·7. The chief source of the emerald is Colombia, where it occurs in pockets in a limestone. Elsewhere they are found in mica-schist, talc-schist, and topaz rock.

Oriental Cat's-eye.—Variety of Chrysoberyl. Oxide of beryllium and aluminium, $BeOAl_2O_3$. Crystallised in complex forms of the orthorhombic system; more usually in water worn pebbles. Translucent; colour, from pale yellow to dark brown, and pale green to deep olive. Chatoyant; characterised by a movable internal opalescent band of white or rarely yellow light. H., 8·5. G., 3·8. Chief source is Ceylon, where it is found in river gravels.

Alexandrite.—Variety of Chrysoberyl. Oxide of beryllium and aluminium, $BeO.Al_2O_3$. Crystallised usually in twins of the orthorhombic system; also in rolled pebbles. Transparent. Colour, emerald green, changing in artificial light to raspberry red. Very rarely chatoyant. H., 8·5. G., 3·7. Occurs in mica-schist in the Ural mountains; and in river gravels in Ceylon.

Opal.—Precious opal is a variety of common Opal. Hydrated silica, $5SiO_2.2H_2O$. No crystalline form; occurs massive, filling small veins and hollows in the parent rock. Translucent. Colour, milky white, exhibiting a magnificent play of prismatic colours on turning through a small angle. Rich red tints are most highly prized. Some opals lose their colour after exposure for some little time, and are therefore of very little value. H., 5·5 to 6. G., 2·1. The best opals come from Queensland and New South Wales where they occur filling small veins in sandstone and trachyte and steam holes in the latter. Found also under similar conditions in Hungary and America.

4885.—Opal, Eromanga, Qld.

Turquoise.—Hydrated phosphate of aluminium, copper, and iron; formula uncertain. No crystalline form; occurs massive in veins or nodules. Opaque. Colour, sky-blue, greenish blue, or green, the first-named being the most valued. Many turquoises fade so easily as to be practically valueless. H, 6. G., 2·7. Chiefly obtained from Persia, where it occurs in veins and nodules in trachyte and slate. Occurs largely in the United States and elsewhere in porphyry, trachyte, slate, and sandstone.

Semi-precious Stones.

Zircon or Hyacinth.—Silicate of zirconium, $ZrO_2.SiO_2$. Crystallised in combinations of pyramid and prism of the tetragon system; also in water-worn pebbles. Transparent; crimson, yellowish-red, amber yellow. H., 7·5. G., 4·4 to 4·8. Ceylon and New South Wales yield the best hyacinths. They occur in river gravels or in situ in syenite, granite, and other crystalline rocks.

Peridot (Precious Olivine).—A variety of Chrysolite. Silicate of iron and magnesium, $2(MgFe)O.SiO_2$. Occasionally crystallised in combinations of orthorhombic prism and pyramid; usually in water-worn pebbles. Transparent; yellowish-green in colour, the deeper the tint the more valuable the stone. H., 6·5. G., 3·4. Occurs chiefly in river gravels in the Levant, Brazil, and elsewhere.

Tourmaline.—Transparent variety of ordinary tourmaline. Composition very complex; a silicate of aluminium, boron, iron, etc. Crystallised in combinations of prism and pyramid of hexagonal system; also in water-worn pebbles. Transparent; colour red, pink (*Rubellite*), green of various shades, blue (*Indicolite*), yellow. H., 7·5. G., 3·1. Occurs chiefly in granitic rocks carrying lithia mica; also in river gravels. Obtained from Siberia, Brazil, United States, Ceylon, Kangaroo Island, etc. Imperfect specimens have been received from Ravensthorpe in this State.

5293.—Rubellite, Ravensthorpe.

Topaz.—Precious variety of ordinary Topaz. Fluosilicate of aluminium, $Al_2O_3(O.F_2).SiO_2$. Crystallised in combinations of orthorhombic prism and pyramid, with perfect basal cleavage; also in water-worn pebbles. Transparent, usually wine-yellow, but also light and dark red, pale blue, pale violet, or colourless, H., 8. G., 3·5. Occurs usually in gneiss, granite, or pegmatite, and in river gravels. Gem topaz comes from Brazil, Siberia, United States, etc. Pale blue topaz has been collected at Londonderry in this State.

4450.—Blue Topaz, Londonderry.

Aquamarine and **Beryl** are transparent varieties of common Beryl, the former of a pale green or pale blue colour, the latter yellow. Except in colour they are identical with Emerald, *q.v.*

Garnet.—Gem varieties of several mineral species belonging to the Garnet Group. Three species are used as gems:—*Almandine (Carbuncle)*, Silicate of aluminium, and ferrous iron, $Al_2O_3.3FeO.3SiO_2$. Claret coloured and most valuable of garnets. *Pyrope*, silicate of aluminium, magnesium, and iron; $Al_2O_3.3(MgFe)O.3SiO_2$. Blood red. *Essonite* (sometimes called *Hyacinth*). Silicate of aluminium and calcium. $Al_2O_3.3CaO.3SiO_2$. Yellow, orange, or brown.

Garnets are found crystallised in forms of the isometric system, the commonest form being the dodecahedron; also in water-worn pebbles. Transparent or semi-transparent; colours as above. H., 7 to 8. G., 3·5 to 4·1. Occurs usually in granite, gneiss, mica schist, or chlorite schist, or in river gravels. Very widely distributed. Fine coloured garnets have been received from near Uaroo in this State.

Spodumene.—Transparent variety of ordinary spodumene. Silicate of aluminium and lithium $Al_2O_3.Li_2O.4SiO_2$. Crystallised in combinations of prism and pyramid of monoclinic system, with strong prismatic cleavage. Transparent. Colour greenish yellow,

rich green (*Hiddenite*), amethyst (*Kunzite*). H., 7. G., 3·1. Occurs usually in granite, pegmatite, or gneiss. Chief sources are Brazil and North Carolina.

Jade (Greenstone).—Partly a variety of Jadeite, which is a silicate of aluminium, sodium, and calcium, $Al_2O_3.(Na_2Ca)O.4SiO_2$. Partly a variety of Actinolite, a silicate of calcium, magnesium, and iron, $CaO.3(MgFe)O.4SiO_2$. Occurs massive with internal crystalline structure. Translucent; dark or light green, yellowish green. H., 6 to 7. G., 3·0. to 3·3. Occurs usually in rounded masses in river beds, or in weathered serpentine rock masses. Chief sources, China, Burmah, New Zealand, Central America.

Crocidolite.—A mixture of anhydrous and hydrous silica with more or less silicate of iron, resulting from the partial or complete alteration of true Crocidolite, which is a silicate of iron and sodium. Compact massive with greater or less fibrous structure. Translucent to opaque, chatoyant. Colours, indigo with light blue ray (*Hawk's Eye*); brown with yellow ray (*Tiger's Eye*); yellow with pale yellow ray; pale green with white ray. H., 6 to 7. G., 2·7 to 3·1. Occurs in veins in igneous rocks in Griqualand and elsewhere in South Africa. Excellent specimens have been received from Yarra Yarra Creek, Murchison District, in this State.

5063/4.—Crocidolite (Tiger's Eye, etc.), Yarra Yarra Creek.

Chalcedony.—Massive cryptocrystalline variety of quartz, SiO_2. Appearance subject to wide variation from the presence of small proportions of impurities. The chief ornamental varieties are: *Carnelian*, translucent of various shades of red, often striated. *Agate*, translucent and variegated, various shades of yellow, red, brown, purple, etc. *Onyx*, translucent, in plain parallel bands of white and black, or brown. *Heliotrope* or *Bloodstone*, translucent, green with blood red spots. *Jasper*, opaque, in bands of bright red, yellow, brown, white, and black. The hardness of the various varieties of chalcedony is 7, specific gravity 2·6. Chalcedony occurs in nodules in ancient lavas, in veins in various rocks, and in pebbles in streams, etc.

3695.—Jasper, Marble Bar, Coongan River.

Moonstone.—Variety of Orthoclase. Silicate of aluminium and potassium, $Al_2O_3.K_2O.6SiO_2$. Crystallised in monoclinic prisms; usually in water worn pebbles. Semi-transparent, opalescent. Colourless or faintly blue. H., 6. G., 2·6. Usually found in pebbles in streams in granite country, especially in Ceylon. Some good moonstones have been found at the mouth of the Bowes River, in this State.

4792.—Moonstone, mouth of Bowes River.

Sunstone or Aventurine.—Variety of Oligoclase. Silicate of aluminium, sodium, and calcium, $2Al_2O_3.Na_2O.CaO.8SiO_2$. Crystallised in forms of the tryclinic system. Translucent, brown with golden spangles. H., 6. G., 2·7. Occurs in igneous rocks, especially in Norway.

Aventurine, Tvedestrand, Norway.

MINERAL WATERS.

Mineral waters may be described as those natural spring waters which contain in solution either constituents rarely found in surface waters, or else exceptionally large proportions of mineral matter of any kind. They are of value either for medicinal purposes or else, owing to their pleasing taste, for table use.

Medicinal waters are chiefly characterised by the presence of magnesium salts, iron salts (Chalybeate waters), lithium salts, sulphides, or sulphates of soda and potash. Of these probably those containing lithium or iron would be found the most valuable commercially. Magnesian waters are common everywhere especially in the interior of Western Australia. They are unmarketable except when they bear the name of some well known European spring such as Friedrichshall, Kissingen, etc.

Table waters of good quality are in considerable demand. They should be sparkling and of good flavour and should therefore contain free carbonic acid and alkaline carbonates, with comparatively little salt, magnesium compounds, or alkaline sulphates. It is essential that they be quite free from sulphuretted hydrogen or sulphides, whilst the presence of some lithium is a decided advantage. The following table gives the composition of the only Australian mineral waters at present utilised, and will serve to show what composition is desirable in a water for the Australian market:—

Source.	Helidon Spa, Helidon, Q.	Zetz Spa, Ballimore, N.S.W.	Koomah Spa, Cooma, N.S.W.	Mittagong Spa, Mittagong, N.S.W.
Use.	Table.	Table.	Table.	Chalybeate medicinal.
	Parts per 1000.			
Potassium chloride ...	...	...	...	·0291
Sodium chloride ...	·0428	·0988	·072	·0308
Magnesium chloride ...	...	...	...	·0185
Sodium bicarbonate ...	4·7883	2·6157	·647	...
Potassium bicarbonate	...	·1833	·245	...
Lithium bicarbonate ...	·0704	·0007	*nil*	...
Magnesium bicarbonate	·0837	·1337	·320	·0320
Calcium bicarbonate ...	·1701	·1625	·774	·0291
Strontium bicarbonate	...	trace	strong tr.	...
Iron bicarbonate ...	...	·0100	*nil*	·0855
Silica	·0041	·0040	·008	...
Alumina	...	trace	trace	...
Free carbonic acid gas	abundant	abundant	abundant	present

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By Authority: Wm. Alfred Watson, Government Printer, Perth.

Annual Reports—*continued.*

3. Progress Report for the Year 1899, containing—

Summary Report; The Staff; Field Work; Principal Results of the Year's Field Operations; Laboratory Work; Mineral Collection; Notes on the Greenbushes Tinfield; Boring for Water at Mulgarrie; Boring for Water at Hayes' New Find; The Geology of the Bardoc District; On the Development of Mining in the locality of Donnybrook; The Geology of the North Lead, Kanowna; The Kanowna Great Boulder G.M.L. 885x; Exhibitions; Mineral Waters; Composition of Native Gold; Greenbushes Tin Ore; Cobalt Ores; Menzies Goldfield; Kalgoorlie Goldfield; Coolgardie Goldfield. Price, 1s. **1900.**

4. Progress Report for the Year 1900, containing—

Summary Report; The Staff; Field Work; Principal Results of the Year's Field Operations; Kalgoorlie Goldfield; Phillips River Goldfield; Gold Finds on the Preston and Ferguson Rivers; The Present Condition and Future Prospects of the Greenbushes Tinfield; Boring for Coal near Albany; North Lead, Kanowna; Bulong Deep Leads; Coolgardie Deep Leads; Alluvial Deposits, Donnybrook Goldfield; Subsidy to the Norseman Gold Mines, Ltd.; Gascoyne District; Extension of Artesian Water-carrying Strata from South Australia; Laboratory Work; Office Accommodation. Price, 1s. **1901.**

5. Progress Report for the Year 1901, containing—

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6. Progress Report for the Year 1902, containing—

Administrative Report; The Staff; Field Work; Lab Mineral Collection; Principal Results of the Year tions. *Mineral Resources*—Iron Ore Deposits o tralia; Diatomaceous Earth, Wanneroo; The R ous Deposits of the Warren and the Donn *M.L.A.,* Lennonville, Boogardie, and Mount Magnet ton and Broad Arrow; Queen Margaret G *Water Supply*—Wyndham; Metropolitan Supply; Winning Pool, Gascoyne Rive Fremantle, Hampton Road; Northampt *d 13 Figures.*

7. Progress Report for the Year 1903, contain

Administrative Report; the Staff; Fie Palæontological Work; Geologica cations; Geological Map of We of the Year's Field Operati Goldfield; Murchison Goldfie Leonora; Edjudina-Yunda wairie and Davyhurst; A Irwin River Coalfield; C Nullagine; State Aid fo H. gine; Miscellaneous Mi Site; Canning River TING GOVERNMENT PRINTER. Eucla Division; Pe 1905

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IX. The Geological Features and Mineral Resources of Northampton: by A. Gibb Maitland, with Appendices by H. P. Woodward, John Provis, and E. S. Simpson. With a map. 1903.

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XIV. The Ge[illegible]gy and Mineral Resources of a part of the Murchison Goldfield: by C. G. Gibson., B.E., Assistant Geologist. With nine maps and eight figures. 1904.

[illegible] Preliminary Report on the Geological Features and Mineral Resources of the Pilbara Goldfield: by A. Gibb Maitland, Government Geologist. With eight maps and 25 figures. 1904.

[illegible] Mineral Production of Western Australia up to the close [illegible]903: by A. Gibb Maitland and C. F. V. Jackson. With [illegible] 1904.

[illegible] and Auriferous Deposits of Southern Cross: by Chas. [illegible]n, B.E., Assistant Geologist. With a map. 1905.

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[illegible]ns to the Geology of Western Australia, [illegible]rofessor Howchin. [illegible] A. Gibb Maitland, W. D. Campbell, and

[illegible]sser known portions of the Kimberley [illegible]nd C. G. Gibson. With a map.

[illegible] Survey Office, Perth, Western

A. Gibb Maitland

1905.

WESTERN AUSTRALIA.

GEOLOGICAL SURVEY.

BULLETIN No. 20.

FURTHER REPORT

ON THE

GEOLOGICAL FEATURES AND MINERAL RESOURCES

OF THE

PILBARA GOLDFIELD,

BY

A. GIBB MAITLAND,
Government Geologist.

Issued under the authority of the Hon. R. Hastie, M.L.A., Minister for Mines.

With Three Geological Maps, Four Mining Plans, and 13 Figures.

PERTH:
BY AUTHORITY: A. CURTIS, ACTING GOVERNMENT PRINTER.
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(*b.*) Possibility of obtaining a Supply of Artesian Water at Men

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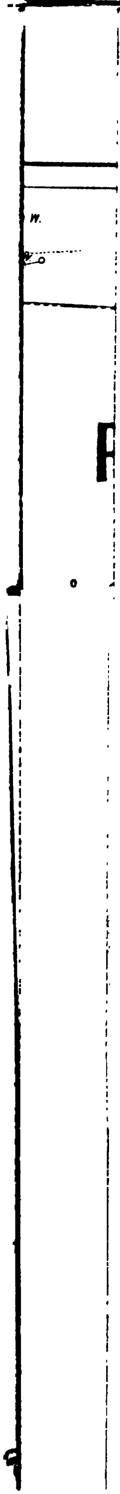
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PREFATORY NOTE.

THIS report makes a further instalment to the descriptions of those mining centres of the Pilbara Goldfield referred to in Bulletin No. 15.

This report includes full details with reference to the Nullagine, Warrawoona, and Marble Bar fields, and is accompanied by geological and mining maps, without which the descriptive portions would be well-nigh unintelligible.

As in the previous season's field work, I was associated throughout with Mr. H. W. B. Talbot, Field Assistant, who rendered important assistance in the preparation of the various maps and plans.

The Index to names, places, reefs, etc., occurring in the report has been prepared by Mr. P. J. Atkins, Clerk of the Geological Survey.

A. GIBB MAITLAND,

Government Geologist.

Geological Survey Office,

Perth, 1st June, 1905.

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FURTHER REPORT

ON

The Geological Features and Mineral Resources

OF THE

PILBARA GOLDFIELD.

PART I.

Descriptive Geology.

Arriving at Port Hedland on the 30th of June in order to continue the examination of the different mining centres left untouched during the previous season, I travelled by coach as far as Marble Bar, and joined the camp, which was in charge of Mr. Talbot, on the 5th of July.

Leaving the camp at Duffer's Creek, we travelled northwards as far as the junction of Talga Creek and the Talga River. From the camp a conspicuous hill was observed 420 feet by aneroid in height and bearing 56 degrees from it. This hill forms the summit of a very long range extending northwards from the Talga Talga workings; it is composed of transmuted basic igneous rocks, intersected by laminated quartz veins. These foliated rocks dip westward at angles of from 40 to 60 degrees; associated with them are some green rocks, which weather very much like limestones; they are, however, identical with those basic igneous rocks, the original minerals of which are replaced by carbonates, so common in many parts of the district.

From this camp we travelled to a gorge known as Kitty's Gap, excavated in that laminated jaspideous quartzite, which extends from Doolena Gap to Bamboo. From camp to the gap, the whole country traversed is greenstone and its derivatives, except for about a mile of granite, which in all probability is an off-shoot from the Moolyella mass.

After getting clear of the Gap, the northern face of the range was skirted as far as Coppin's Gap. The country at the foot of the northern face of the range exposes a gneissic granite, the strike of the foliation of which is parallel to that of the laminated quartzite which makes up the range.*

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* Bulletin No. 15, pp. 25, 26.

From Coppin's Gap we travelled northwards towards the point of a conspicuous range of hills which lay between us and Bamboo Creek. The highest summit of the hill rises to a considerable height above the plains, which are everywhere underlaid by granitic gneiss and allied rocks. The rocks forming the hills consist of volcanic agglomerate dipping at angles of about 20 to 30 degrees to the east, and passing beneath the sedimentary beds of what there are good reasons for believing to be the equivalents of the Nullagine Series. Associated with these agglomerates are greenish grey beds of either lava or ash. Travelling across to Bamboo Creek, strata on a somewhat higher horizon are traversed; they consist of coarse conglomerates, and fine-grained sandstones, some beds of the latter of which have been quarried to a limited extent. Some of these conglomerates and grits are traversed by vertical quartz veins, some of which are of considerable horizontal extent. The general strike of these "buck-looking" quartz veins is 16 degrees. From our camp at a fine pool of water near a boundary fence (? Coppin's) to the now all but deserted township of Bamboo, the road follows the edge of the top of volcanic beds of the Nullagine Series.

The country in the more immediate vicinity of this centre having been previously fully described* need not be repeated.

From Bamboo to the foot of Mount Edgar, *via* Jones' Well, the country is made up of granite of the Moolyella type, intersected by dykes of felsite and diabase in addition to quartz veins.

Mount Edgar, one of the most prominent landmarks in the vicinity, rises to a height of about 300 feet above the base, and consists of a bluish grey basic rock [**5753**] in the form of a dyke. In the vicinity of Mount Edgar, the staple formation of the district (granite) is traversed by two sets of felsite dykes, one set with a general strike of north 30 degrees east, and the other north 30 degrees west. Both of these sets of dykes are traversed almost at right angles by quartz reefs, in this respect they are somewhat analogous to the system of quartz reefs and dykes of the Charters Towers Goldfield in Queensland, with which I am familiar.

From Mount Edgar, we steered across country for Warrawoona, crossing *en route* a very conspicuous greenstone dyke, at the foot of the northern side of which the Talga River flows.

This dyke, which has a general bearing of 334 degrees and 163 degrees, rises to a considerable altitude above the plain, and forms a very conspicuous feature in the landscape. So far as can be seen, the dyke is vertical and attains a thickness of about 20 feet; it traverses granite country. Several other parallel dykes of a somewhat similar nature can be seen in the vicinity.

Between this point and Warrawoona, two other parallel dykes are crossed. The granite country ends about a mile or so north of Warrawoona, and gives place to those beds, a detailed description of which is given on a later page.

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* Bulletin No. 15, pp. 26, 51-61.

The mapping and examination of Warrawoona, having been completed, we struck camp and travelled in the direction of Yandicoogina as far as Gum Well. The country between the camp and the well is underlaid by granite, which has a rude foliation, the general strike of which is parallel to that of the schists, which forms the high ground of the range, near the foot of which the main road traverses. At a point about two miles west of the well, a very prominent diabase dyke is crossed, in addition to two others of much smaller dimensions; the larger dyke in all probability represents the extension of the one crossed between Mount Edgar and Warrawoona. The large dyke near Gum Well makes a very prominent feature in the landscape, and can be followed by the eye across country for a considerable distance. A traverse on foot was made from Gum Well to the range, and at one spot the large coarse-grained diabase dyke was shifted for a horizontal distance of 120 feet west by a fault bearing 112 degrees. This fault is now occupied by a quartz reef. A parallel diabase dyke of smaller dimensions has also been subject to the same amount of western displacement.

From Gum Well, a conspicuous Gap in the main range can be observed. The position of the Gap is fixed by the following bearings:—Gum Well, 31 degrees 30; Mount Edgar 41 degrees; Trig. Station G. 23, 276 degrees; and Horrigan's Peak, 302 degrees.

The Gap has been carved out of a bold quartz reef, which measures from 30 to 40 feet in width, and is of very considerable horizontal extent; for it has a length of about four or five miles in a direction of 118 degrees, and about a mile in the direction of 298 degrees. The quartz reef is evidently along a line of fault (?) which separates the granitic rocks from the Warrawoona Beds, which latter at this point occupy a width of about two miles. The large greenstone dyke previously alluded to abuts abruptly against the quartz reef of the Gap, but does not cross it. The Trig. Station G. 23 is formed of another large quartz reef, identical with that forming the Gap, and equally wide and persistent longitudinally. Both form remarkably pronounced features in the landscape.

The country between Gum Well and Yandicoogina is of granite intersected with numerous greenstone dykes.

From Yandicoogina, exigencies of travel rendered it necessary to travel as far as the De Grey (Nullagine) River *via* the main Elsie Road.* We camped on a creek, at an altitude of about 200 feet above Yandicoogina, which flowed in a general direction of north 70 degrees east. Advantage was taken of the short spell of daylight after arriving to examine the country in the vicinity. About three miles north 70 degrees east from camp was a conspicuous escarpment, the summit of which seemed to afford a good opportunity of examining the surrounding country, and a traverse was made in that direction.

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* Bulletin No. 15, p. 27.

On the eastern bank of the creek, upon which the camp was pitched, is a good exposure of sandstones and shales (Nullagine Series) dipping at 20 degrees in a direction north 30 degrees east and traversed by several small faults. Sandy beds cover the surface of the country as far as the foot of the escarpment.

The bed forming the summit of the hill is a thin bed of quartzose conglomerate, containing pebbles and fragments of those laminated quartz veins so conspicuous in other portions of the district. The general dip of these sedimentary rocks which must, as seen from the hilltop, occupy a large area of country, is in the direction 228 degrees at angles varying from 8 to 10 degrees.

Having reached the De Grey (Nullagine) River, it was followed to the junction of Cook's Creek. At a point about six or seven miles in the river above the crossing of the Elsie Road, granite emerges from beneath the sedimentary rocks and occupies the country for some considerable distance. The granite is traversed by numerous quartz veins which have a general bearing of about 174 degrees.

Cook's Creek was followed up to the point at which it is joined by Mosquito Creek, passing the Black Range of the maps *en route*. The Black Range is a long razor-backed ridge of laminated quartz of the usual type. Having camped on Mosquito Creek some miles below the township, a visit was paid to the Parnell Mine.* The country between the camp and the township of Mosquito showed the staple formation to consist of highly-inclined grits, sandstones, and shales (or slates), with numerous quartz veins along the bedding planes (Mosquito Creek Beds).

In the vicinity of the lower (Mosquito Creek) well, two conspicuous rugged hills of granite (?) rise from amongst the sedimentary beds. From a distance these hills bear a remarkable resemblance to the granite hills of Mosquito township,† although the area these rocks occupy is not nearly so great as at the township.

From the camp at Mosquito Creek we travelled along the old 40-Mile Road to the crossing of Sandy Creek, which was followed down to its junction with the Nullagine River. The whole section down to the Nullagine River showed the staple formation to be of grits, shales, and conglomerates (Mosquito Creek Series) inclined at high angles. Where Middle Creek joins Sandy Creek is a vertical bed of fine-grained conglomerate.

The Nullagine (De Grey) River was followed up to the township of Nullagine, and the staple formation consisted of highly-inclined sedimentary rocks of the Mosquito Creek Series. On the western bank of the Nullagine River, at the junction of Taylor's Creek, is a large dyke of gabbro, striking about 230 degrees. The dyke, which in all probability has some intimate connection with that which makes such a prominent feature in the geology of the township of Nullagine, is about half-a-mile in width at this point.

* Bulletin No. 15, p. 80. † Loc. cit., p. 78.

Having completed the mapping of Nullagine, a full description of which is given on a later page, we followed the main road to Marble Bar, passing the almost deserted mining centre of Wyman's Well *en route*. The country round Wyman's Well, originally known as Salgash, is identical in its geological features with Warrawoona, of which it merely forms the westward extension.

A twelve-acre lease, the Phœnix G.M.L. 624, owned by Messrs. Anderson and party, and a three-men's quartz claim owned by Messrs. Swanson and Morris Bros., represent the mining activity prevailing.

Marble Bar was reached on the 29th of September.

PART II.

Descriptions of Individual Mining Centres.

A.—NULLAGINE.

(*With a Geological Sketch Map and Section, and a Plan of the Nullagine Conglomerates Gold Mines.*)

The mining centre of Nullagine is situated 55 miles to the north-north-west of Marble Bar, upon the Nullagine River, about 90 miles above its junction with the Oakover; its relative position is shown on the Locality Map of the Pilbara Goldfield, which forms the frontispiece to this report.

Interest attaches to this district on account of the occurrence of gold in certain sedimentary rocks, which bear a close resemblance to the auriferous conglomerates of the Rand (South Africa), better known as the Banket deposits. These (Nullagine) auriferous conglomerates, which seem to form lenticular masses, occur in the basal members of the Nullagine Series* as developed in the ranges to the north-west of the township.

It being an important problem in economic geology to ascertain the extent, etc., of these auriferous conglomerates, as well as the quartz reefs in the underlying series of beds, a belt of country embracing what is, as at present understood, the productive area was mapped upon the scale of 20 chains per inch. The ground covered by this work comprises a belt of country about four miles in length and breadth, which is depicted upon the Geological Sketch Map (Plate I.).

As by far the larger portion of this area was practically a blank upon any of the existing maps, operations had to be commenced by preparing a plan of the vicinity of the mines. This work was accomplished by the aid of a plane table and tape measure; it would, however, have been a decided advantage had time permitted of a contour map of the district being prepared. The local representatives of the British Exploration Company, the principal lease owners in the vicinity, courteously placed at my disposal their topographical plan of the Conglomerate Mines; a reduced copy of this, embodying some geological additions by myself, forms Plate II.

A comparison between this map and the 40 chain lithograph, L 76, issued by the Department of Mines, discloses the fact that considerable violence had to be done to the position of the

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* Preliminary Report on the Geological Features and Mineral Resources of the Pilbara Goldfield, by A. Gibb Maitland. Geol. Surv. Bull. 15. Perth: By Authority: 1904, p. 10.

Nullagine River. On lithograph, L 76, it will be noticed that there are two Nullagine Rivers, the most northerly approximately parallel to the Marble Bar Telegraph Line, and the other skirting the northern boundary of the extinct leases 57L and 58L. The true course of the river is that shown on the Geological map.

It is essential, in the public interest, that at any rate the principal water-courses in mining districts especially, should be traversed and their position laid down on the published maps with such a degree of accuracy as the scale employed will admit. Tacheometric methods afford a reliable, cheap, and accurate method of this class of work being carried out expeditiously. A great deal of time and labour is involved in preparing topographical maps, upon which the areas of the different formations, the geological boundaries, the trend of the outcrops of the different ore deposits, etc., could be delineated, which could be much more profitably expended by a geologist in other directions.

In both its physical and geological aspects, the district falls naturally into two distinct portions, which lie respectively to the north-west and south-east of the Nullagine River.

The north-western portion is that occupied by the sandstones, grits, conglomerates, and interbedded volcanic rocks of the Nullagine Series. This series, which presents a plateau-like appearance, exhibits a bold escarpment when viewed from the south-east, and certain of the harder beds stand out in bold relief, presenting mural faces at different levels. The tableland has been carved out into deep canon-like gorges and ravines, of which Beaton's Creek, and the One Mile Creek, are typical examples. The course of many of these creeks, and their tributaries appears to have been in the main determined by the trend of the system of master joints, by which the Nullagine Series has been intersected. An excellent example of this rectangular system of jointing occurs in Beaton's Creek about a mile and a-half above its junction with the Nullagine River, just within the western border of the geological map.

The greater part of the country lying to the south-east is formed of an open rolling plain, the monotony of which is broken by a very conspicuous serrated ridge of gabbro (?). This dyke lies about two miles to the west of the township of Nullagine. The Nullagine River cuts through the ridge at a point about three miles below the township. This gabbro dyke rises to a considerable height above the level of the surrounding country and forms a very conspicuous feature in the landscape. This plain is underlaid by the rocks of the Mosquito Creek Series, which formation carries all the auriferous reefs yet worked in the district.

The whole of the country lies within the watershed of the Nullagine River and its tributaries; the two most important of which are Beaton's and Kadjebut Creeks.

History.

Very little appears to have been officially recorded of the early history of the Nullagine district. It seems, however, that the first discovery of gold at Nullagine was made by Mr. N. W. Cook, in the year 1886, as a reward for which he received, two years later, a sum of £250 from the Government.

The spot at which the original find was made lies at the western extremity of a long, narrow, laterite tableland, in close proximity to several quartz reefs; the position of this spot is indicated on the Geological Sketch Map of Nullagine. (Plate I.)

The erection of a ten-head battery in 1895 at Nullagine, where the first crushing of 184 tons yielded 210ozs. 16dwts. of gold, appeared to have given a great impetus to mining, for the Warden of the field, writing in July of that year, reported:—"Quite a boom in leasing has commenced."*

The following year, the Inspector of Mines for the Northern Goldfields stated:—"At the Nullagine, quartz reefing (which has only been inaugurated during the past 18 months) is making rapid advances, crushings having yielded from 2ozs. to 8ozs. per ton, while the acquisition of a large area of conglomerate holdings by an English company marks a new era in the history of the district.†"

The progress of Nullagine during the year 1897 is thus alluded to by the Warden in his Annual Report to the Minister for Mines:—"Besides alluvial digging and quartz reefing, gold is obtained from conglomerate lodes with payable results. There is one ten-head battery, and two more are in course of erection. Water is obtained at an average depth of 50 feet. The yield of gold for the year is 982ozs. There are regular consignments of alluvial gold from Nullagine, of which I have no record; but, from information obtained from the business people, I should say that, at the lowest estimate, these would amount to 600ozs. per annum."‡

Writing on the advances made on the Pilbara Goldfield during 1898, the Warden thus alludes to the progress of Nullagine:—"The North-West Australian Goldfield, Ltd., at Nullagine, are showing their confidence in their conglomerate lodes by supplementing their crushing machinery and laying down tramways, and thus, by working on a large scale, endeavour to decrease expense and make their properties pay."§

No mention is made of the progress of Nullagine during 1899, 1900, and 1901 in the reports of the Warden, as published in the annual reports of the Mines Department; for 1902, however, it is

* Supplementary Report on the Department of Mines, 1st October, 1895. Perth: By Authority, 1895, p. 4.

† Pilbara and West Pilbara Goldfields, 1896. S. J. Becher. Report of the Department of Mines for the Year 1896. Perth: By Authority, 1897, p. 36.

‡ Report of the Department of Mines for the Year 1897. Perth: By Authority, 1898, p. 23.

§ Report of the Department of Mines for the Year 1898. Perth: By Authority, 1899, p. 19.

stated:—"A large amount of good and useful development work is being done in the Nullagine District, where a further ten-head of stamps is being erected on the British Exploration and Development Company's property, which, when completed, will enable them to run 15 head, and for which purpose they are carrying out a water scheme which, when completed, will bring water a distance $1\frac{1}{4}$ miles from the river to the mine. Later on another 20 head is proposed to be erected."*

The year 1903 was a very quiet one in Nullagine n so far as any mining was concerned, and no mention is made of its progress in the Annual Departmental Report for that period.

General Geology.

The following represents in tabular form the geological formations in the district embraced by the area of the map. The stratified rocks are arranged in geological sequence:—

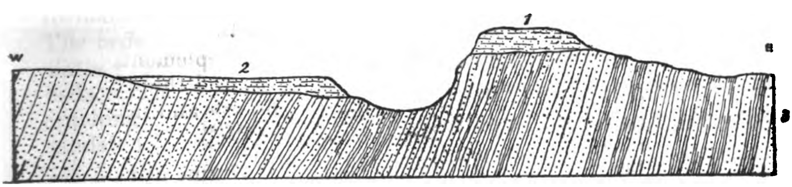
Alluvial deposits.
Laterite.
Nullagine series. Quartzites, grits, conglomerates and interbedded igneous rocks.
Unconformity.
Mosquito Creek beds.—Sandstones, fine conglomerates and shales.
Greenstone dykes.

Alluvial Deposits.

The banks of the Nullagine River and its tributaries are skirted by a variable width of alluvium, the full extent of which has been shown on the geological map. The greatest width attained by the alluvium is about 50 chains, but in no case does it reach any great thickness.

The south-eastern banks of the Nullagine River show a considerable extent of alluvium at a much greater elevation than that of the present water-courses. This is depicted in Fig. 1. This

Fig. 1.



SECTION ACROSS THE NULLAGINE RIVER NEAR TOWNSITE. PILBARA G.F.

1. OLDER ALLUVIUM. 2. NEWER ALLUVIUM. 3. SANDSTONES, GRITS AND SHALES.

section shows the remains of an older alluvium laid down at a time when the Nullagine River flowed at a slightly higher level than now.

* Report of the Department of Mines for the Year, 1902. Perth: By Authority, 1903, p. 44.

Writing in the year 1890, Mr. H. P. Woodward says, with reference to the alluvial deposits of Nullagine, that * :—

"Three classes occur; 1st, the alluvium of existing creeks; 2nd, the alluvium of older creek beds, but in conjunction with the present streams; 3rd, older alluvial deposits or deep leads bearing no relation to existing streams or configuration of the country. . . The older alluvial deposits are found in the river flats, where the auriferous gutters are crossed and recrossed by the present streams. The sinking here is about 10 feet, and very hard work, owing to the fact that the deposits that overlay the dirt are cemented masses of quartz and boulders of other hard rocks. . . . The deep leads are cut across by the present valleys, and can be traced from hill to hill. Here the sinking is very variable in depth, the whole gutter in some places appearing on the side of a cliff where the work merely consists in driving, while in other places shafts up to 60 feet or 70 feet have to be sunk to work the same lead. Up to the present only one of these leads has been discovered, but there cannot be the least doubt that more will be found when the small hills between the conglomerate range and the creek are thoroughly prospected. All three of these deposits are very rich, but no one can estimate the quantity of gold with any degree of accuracy, as so much leaves the colony without ever being reported; but there is no doubt that more has been taken from this field than from any other in the colony."

It is not quite clear from what can at present be seen in any of the sections exposed in the neighbourhood of Nullagine, that what are described above as "deep leads" are such; the impression left upon my mind is that they merely represent weathered outliers of the basal members of the Nullagine Series.

Table showing the Yield of the Alluvial and Superficial Deposits of the Nullagine District generally.

Year.	Gold.
	ozs.
1897	No data.
1898	1,000·00
1899	729·79
1900	27·00
1901	831·02
1902	390·67
1903	288·30
1904	403·24
Total	**3,670·02**

* Annual General Report of the Government Geologist for the Year 1890. Perth: By Authority, 1891, p. 25.

Laterite.

A very noticeable geological feature of the area, is the occurrence of several isolated tablelands of laterite; the area which these occupy has been accurately delineated upon the map of the district. One very important feature which the map, owing to the lack of contour lines, fails to bring out, is the uniform level at which this laterite invariably occurs.

The most conspicuous tableland is that which lies to the south-west of the township, and about a quarter of a mile west of the river bank. The tableland has a length of about a mile and a quarter, and an average width of about 10 chains; it presents a steep bluff, several feet in height, which extends with scarcely any interruption all round the plateau.

This tableland is breached by that tributary of the river which flows into it near Suburban Water Right No. 5. The laterite continues from this point as a narrow strip far beyond the limits of the map. Three other outliers occur to the north of Beaton's Creek, the most conspicuous being that which lies adjacent to the township of Nullagine.

An inspection of the geological map demonstrates that the laterite traverses successively all the geological formations, with the single exception of the modern alluvium.

In its lithological characters, the deposit presents all gradations from ferruginous claystone to pure limonite; the rock itself is very porous, and weathers readily into caverns and cavities of all sizes; in some places the surface of the rock is covered with a glaze of hydrated oxide of iron. When seen in section, it is noticed that the laterite passes by insensible gradations into the underlying strata without any sharp line of demarcation.

Mr. Woodward refers to what is evidently the laterite series as follows: "Another line of flat-topped hills, but lower, extends along the side of the creek, but these are of much more modern formation,* and it is in these that the deep leads are met with. The beds which form these hills rest directly upon the indurated slates,† and pipeclay, soft white sandstone, gypsum, and boulder beds. The wash is often very ferruginous and hard, necessitating crushing. The whole of these beds are capped by a ferruginous sandstone containing large quantities of fossil wood." ‡

It may be noted in this connection that I saw nothing which could be described as fossil wood anywhere in the series, as exposed in the vicinity of Nullagine, this, however, may possibly be due to the fact that at the time the district was visited, work was in full swing, and Mr. Woodward may have had better opportunities for observation than were open to me.

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* The beds of the Nullagine series.—A. G. M.
† The Mosquito Creek Beds.
‡ *Ibid.*, p. 35.

The Nullagine Series.

Sedimentary Rocks.

The Nullagine Series is largely developed in the Pilbara Goldfield, and consists of a great thickness of sandstones, grits, conglomerates, and limestones, some of which are magnesian, together with a series of lavas and ashes and agglomerates of as yet unascertained thickness.

The formation, the base of which is rarely seen, makes a prominent feature in the landscape of the district, and plays a very important part in the geology of the north-west, in addition to being of some economic value by reason of the basal members of the series having been proved to be auriferous in at least two localities many miles apart.

Previous reference to the Series.—In Bulletin 15 full descriptions have been given of the different sections which illustrate the relationship of the Nullagine Series to those beneath,* and therefore need not be repeated.

Mr. H. P. Woodward, in the year 1890, makes the first brief official mention of the auriferous conglomerate of Nullagine in the following terms:—"To the west of this field are hills of nearly horizontally-bedded conglomerate rocks, probably of Devonian Age, in which reef gold occurs in small veins of quartz and ironstone, which follow and indeed fill in all interstices between the larger boulders. They are very rich in places, in fact so rich that it pays to 'dolly,' and the gold in the flat close by is evidently derived from these veins. This deposit is of very great interest, as nothing like it has before been found, for the gold, although occurring in an alluvial deposit, is reef gold and not alluvial, for it has been deposited subsequently to the formation of these boulder beds."†

On a later page of the same report, in the description of the country traversed from Geraldton to Nullagine, Mr. Woodward gives a few particulars with reference to the auriferous conglomerate and its relation to the older strata in the following terms:—"In this conglomerate the gold is alluvial in character, but it is true reef gold, being deposited there subsequently to the deposition of the boulders between which it has been infilled with silica and iron, probably by thermal action. These beds dip at an angle of 12 degrees to the north-west. They vary greatly in character from quartzite to boulder conglomerate, but it is only in the ferruginous beds that the gold is found. This formation is probably of Devonian Age, resting unconformably upon the edges of the clay slates and quartzite conglomerate beds with quartz reefs of the metamorphic series." ‡

The latter portion of this description shows that the violent unconformability separating the beds of the Nullagine Series from those of the Mosquito Creek beds was at least recognised, though not emphasised, by Mr. Woodward fifteen years ago.

* pp. 18, 20, 21, 22, 23, 24, 25, 27, 28, 30, and 31. † Annual Report of the Government Geologist for the Year 1890. Perth: By Authority, 1891, pp. 25-26. ‡ *Ibid.*, pp. 34-35.

Writing in the year 1895, the Acting Inspector of Mines, Mr. S. J. Becher, informed the Minister for Mines that:—"Nullagine, one of the oldest and best districts of the whole field (Pilbara Goldfield), lies about 80 miles south-east of Marble Bar. Geologically, it is perhaps unique. The general character of the country is that of table-topped hills about 200 feet high, intersected by deep ravines, gullies, and valleys, widening out into flats and plains in all directions. In the immediate neighbourhood of the township the main characteristic features are:—First and centrally, flat-topped hills having ironstone formations, as 'crust,' overlying decomposed conglomerate matter; secondly, hills more rounded on top consisting of red and white cement and conglomerate deposits of varying thickness, some of the waterworn quartz being quite boulders in size. The conglomerate contains a great quantity of ferruginous matter, and this apparently carries most of the gold, which occurs in a fine state."

"The central hills seem to have been the result of denudation and decomposition of the material of the surrounding conglomerate and other formations. For the past six or seven years, there has been a steady output of alluvial gold from this field. Every gully has been systematically worked, the wash being screened and then carted down to the pool in the river for puddling and washing. The screenings, etc., have even been reworked at a profit by dry-blowers. It was noticed that the 'runs' of gold extended up the hill sides from out of the creeks and gullies. These runs were followed up the surface rubble for a few inches in depth, being all put through the dry-blowing machines, until the run ceased, when it was found that the original source of the gold was a seam or perhaps a big lode of conglomerate, whose outcrop was on the contour line where the run of gold ceased extending up the hillside. Though alluvial work is still carried on, more attention is now paid to the conglomerate lodes, which are being extensively worked and put through the battery with payable results."

"Of late, too, some very rich reefs have been found a few miles out, in what is locally known as the 'claypan' country. Crushings from the outcrops and superficial works on these reefs are returning from 2 to 4 ozs. per ton, and their prospects of permanency in depth are, it is said, good."

"The conglomerate lodes have attracted the attention of English Capitalists, and there will soon be extensive works thereon in operation. . . . "*

In 1898, Mr. S. J. Becher describes the conglomerates of Nullagine in the following terms:—"In the immediate vicinity of Nullagine township or mining camp, range upon range of conglomerate hills lie to the north-west. . . . The course of the river . . . follows the outskirts of the conglomerate country, keeping on the farther side of the slate country and its

* Report of the Department of Mines for the Year 1895, Appendix 5. Perth: By Authority, 1896, p. 29.

quartz reefs, and forms a marked line of division, as it were, between the characteristic topographical features of the district. . . . . Coming then to the conglomerate ranges, which average in height about 100 to 150 feet above the level of the river flat we find that the hills in the forefront, upon which the chief mine workings are at present situated, appear to be mostly round-backed and strewn with rounded boulders and pebbles. On closer examination, one finds that they consist of bed upon bed of conglomerate, merging into intermediate layers of kaolin. The beds dip universally to the north-west, and strike north-east and south-west. The dip is flat, averaging perhaps 15 degrees. Therefore as one approaches from the south-east the hill-sides exhibit longitudinal sections of the country, and in some cross gorges very complete studies may be made of cross-sections; whilst, where the rounded weathered hill sides slope to the flat, one may notice somewhat regular lines of round boulders and pebbles roughly marking the outcrops of the conglomerate beds. By these indications, and also by following up the runs of alluvial gold until they stopped all along certain horizontal lines, the auriferous conglomerates were originally located and worked by prospectors by means of drifts and tunnels."

"Some of the conglomerate beds contain boulders up to three or four feet in diameter, while others carry nothing bigger than a man's head. These boulders consist of rounded masses of fragments of quartz, trap rocks, and other conglomerates. A peculiar feature about the shape of these is that they are very often somewhat flattened like curling stones. This flattened shape might suggest glacial action, but the writer saw no striæ. These have, the writer understands, proved to be less auriferous than the other beds whose component particles are small. The best gold seems to be obtained from ferruginous veins. The ore now being crushed by the mining companies varies in value, the writer believes, from 10dwts. to 2ozs. per ton, the treatment being by battery and amalgamation alone. The gold is worth £3 17s. 6d. to £4 per ounce. At the time of the writer's visit, in the year 1896, only the decomposed portion of the beds had been worked, but he is given to understand that a vertical shaft has since cut a bed in depth below the zone of decomposition, and that the character of the rock is a very hard greenstone conglomerate, carrying much iron pyrites, samples of which have yielded returns by assay up to 13dwts. per ton."

"Behind these round-backed series of hills, to the westward, the topographical features vary again, and the conglomerate ranges assume an appearance of being terraced, the reason of which becomes evident upon examination. Following up into these ranges an affluent of what is known as the main creek, one enters a gorge with precipitous sides rising to 50 feet in height, and here a very fine cross section of the country may be examined. Here it may be seen that, interbedded conformably with the beds of conglom-

A.

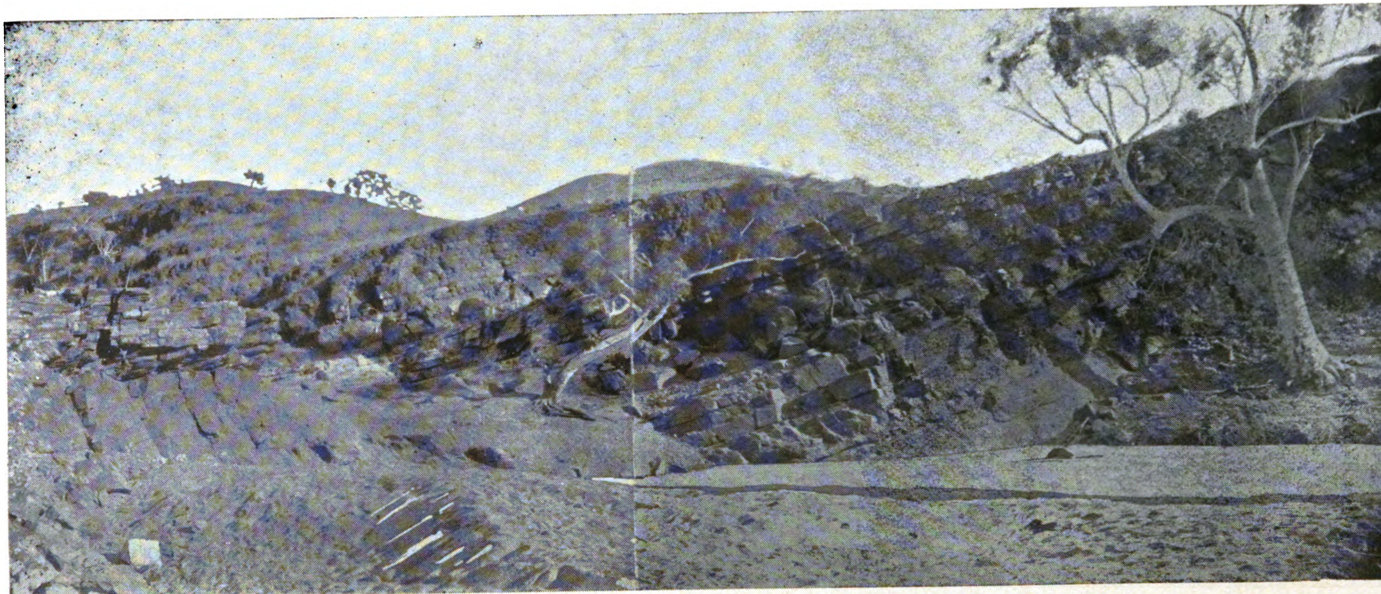


PHOTO.: S. J. BECHER.

Beaton's Pool, showing the Conglomerates and Interbedded Ashes, Nullagine.

erate, there are indurated slates and grits. The former, where long exposed to the action of the atmosphere and water, split off into flags."

"Compared with the above-mentioned series, little or no decomposition has taken place beyond surface-weathering, which accounts probably for the fact that no free gold (to speak of) has been obtained in the gullies, and that the terraced series is not at present recognised as auriferous. Time may prove this. The terracing is due to the unequal effect of weathering on the exposed longitudinal edges of these otherwise undecomposed beds of varying durability."

"As to the age and origin of these interesting Nullagine beds, nothing definite is yet known. . . . ." *

Professor David, writing in 1902 on the Permo-Carboniferous glaciation of Western Australia:—"There is . . . in my possession a photograph (Fig. 5) taken by the late Mr. Becher of the Geological Survey of Western Australia, of a remarkable conglomerate at Nullagine, Pilbara, Western Australia, which so closely resembles in general appearance the Cambrian glacial beds of South Australia as at once to suggest a possible glacial origin for the West Australian beds. They are also associated with a very finely-laminated shaly altered rock, not unlike the Tapley's Hill shales, which overlie the Cambrian (?) glacial beds of South Australia. These Nullagine beds are probably of older palæozoic age (? pre-Cambrian), and should well repay further investigation." †

The finely-banded rock, to which Professor David thus alludes, is probably either one of those lavas or ashes, which lie near the base of the series and are well exposed in Beaton's Creek, and the Nullagine River itself.

In the more immediate vicinity of Nullagine there are several cliff sections which show the mutual relationship of the various members of the series. (Photograph "A.")

In Beaton's Creek, a tributary of the Nullagine River, which it joins at the foot of McFie Street, is a very good section, showing the relation of the interbedded character of the volcanic rocks, forming the basal members of the series.

A portion of this section is shown in Fig. 2.

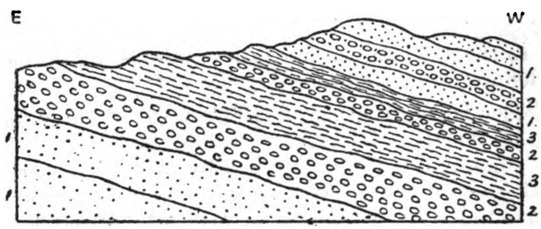
The cliffs near Beaton's Pool expose two beds of ash dipping to the westward at an angle of 17 degrees from the horizon. The uppermost bed attains a thickness of five feet six inches, and is separated by six feet of conglomerate from another ash bed 12 feet thick. In the geological map, owing to the smallness of the scale, this deposit has been treated as one bed. The mapping shows that the bed is merely an attenuated lenticular patch of no very great horizontal extent.

* The Nullagine District, Pilbara Goldfield, Western Australia. Trans. Inst. Min. Engineers (Newcastle-upon-Tyne), 1898. Vol. 16, Pt. 1, pp. 44-52.

† Report of the Glacial Committee. Austral. Assoc. for the Adv. Sci., Vol. 9, 1902, p. 201.

A little distance below the pool is another much thinner bed of somewhat greater horizontal extent; it can be followed northwards as far as the southern angle of G.M.L. 2L. (216) "The Trinity," where it is cut off by the fault which traverses this portion of the district. A good section of the ash is to be seen in the gully to the south of "The Trinity," at a considerable altitude above the level of Beaton's Pool, for the strata rise very rapidly in this direction.

FIG. 2.



SECTION AT BEATON'S POOL PILBARA G. F.
1 SANDSTONE. 2 CONGLOMERATE. 3 ASH.

The uppermost bed of ash [5796], which forms a fall over which the waters of the creek drop into Beaton's Pool, extends about 50 chains to the northward, where it also is truncated by the fault previously alluded to. In the vicinity of the fault, the bed has a slightly increased dip of 20 degrees to the west. A small attenuated portion of it is to be seen on the downthrow side of the fault near the head of one of the branches of Beaton's Creek. It is possibly this bed which occupies the topmost stratum of the synclinal trough occurring on M.L. 1L. There is however no great thickness of ash in this section, the bed evidently thinning out rapidly in this direction.

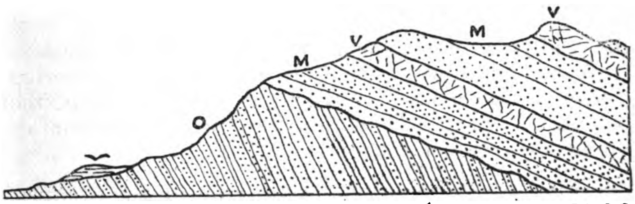
A traverse up Beaton's Creek for about a mile or so above the pool shows the beds overlying the ashes to consist of conglomerates [5797] and grits disposed in a series of gentle folds, with dips varying from 5 to 8 degrees from the horizontal. The cliffs rise to considerable elevations above either bank of the creek, and show good sections of the strata. The beds are traversed by a series of rectangular joints which have proved to be the dominant factor in determining the general direction of the watercourse.

An important section is to be seen on the southern bank of the Nullagine River at a point about 40 chains south-west of Suburban W.R. 5L, which discloses the violent unconformability separating the Nullagine from the underlying series (Fig. 3):—

The basal member of the Nullagine Beds in this section consists of a few feet of grit and conglomerate, overlaid by about 3 feet of ash, the whole dipping at an angle of about 18 degrees to the southwest. These rest upon the upturned edges of the quartzites and

dense shales forming the Mosquito Creek Beds, which latter dip at angles averaging about 70 degrees in a south-west direction.

FIG. 3.



SECTION OF THE NULLAGINE RIVER NEAR W.R. 5L PILBARA G.F.

ALLUVIUM O QUARTZITES & DENSE SHALES (MOSQUITO CREEK BEDS)
V LAVAS & ASHES
M CONGLOMERATES & GRITS. } (NULLAGINE BEDS.)

Some distance higher up the river the conglomerates and grits of the Nullagine Beds are overlaid by acidic lava [**5795**]. These volcanic beds occupy the country as far as Wild Dog Camp, Res. 3328,* about 16 miles above the township, and entirely conceal the sedimentary rocks beneath. In the neighbourhood of Wild Dog, the lavas are somewhat amygdaloidal [**5808**]. In certain portions of the district, the irregularities of the old surface upon which the beds were laid down is such that the volcanic beds often overlap the older rocks.

About four and a-half miles eastward, the volcanic rocks rest directly upon granite, at an altitude of about 200 feet above the well at Wild Dog Camp, the sedimentary rocks beneath being absent. This granite country is traversed by several quartz reefs. A very prominent reef, having a general trend of 248 and 63 degrees with a horizontal extent of a few miles, does not appear to be a fissure vein, as generally understood, but merely a gradual replacement of the surrounding granite by silica along a main line of weakness.

The bedded lavas, which are sometimes vesicular, were followed westwards some miles beyond Trig. Station G 13, on the head waters of the Coongan River; and from their mode of occurrence in the field, it is evident that they rest in this locality upon a very uneven surface.

No opportunity presented itself of tracing the boundary of the Nullagine Series to the south of Wild Dog Camp, but so far as may be judged from Mr. Woodward's descriptions, the formation would appear to extend to a point a few miles to the westward of Bamboo Spring (Res. 1927) on the head waters of the Shaw River, for it is stated "the rocks (near Bamboo Spring) are quartzite and basalt, with veins of chalcedony and inferior opals; the chalcedonies are

* Lands Department Lithograph 16 G.

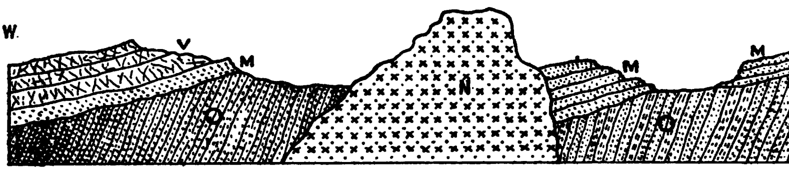
often finely banded, and should be of considerable commercial value, as they can be obtained in large blocks."*

From a personal knowledge of the country, I have very little doubt as to the identity of the strata to which Mr. Woodward refers with those already described.

The road from Nullagine to Wild Dog Spring passes, after getting clear of the town, near Kadjebut Spring, a watering place on the creek of that name. In the vicinity of the spring, there are several sections which give a fair idea of the relation existing between the various rock formations.

The Fig. 4 gives a generalised section of the country in the vicinity of what is known as the rock hole, near Kadjebut Spring.

FIG. 4.



SECTION IN THE VICINITY OF KADJEBUT SPRING. PILBARA G.F.

V. LAVA & ASHES } NULLAGINE SERIES
M. GRITS & CONGLOMERATE }
O. SANDSTONES, CONGLOMERATES & SHALES. MOSQUITO Ck. SERIES
N GABBRO.

On the western side of the large dyke, which at this point attains a considerable thickness, the Nullagine Series is represented practically by lavas and ashes, with a thin bed of conglomerate underlying. The beds rest with a violent unconformity upon the upturned edges of the Mosquito Creek Series. The Nullagine conglomerates and grits abut directly against the dyke along its eastern wall. So far as can be seen, there is no evidence of alteration of the sandstone and conglomerate anywhere along the line of contact between them and the dyke, nor so far as I could detect were there any pebbles of the gabbro contained in the conglomerate. The evidence so far as it goes seems to point to the junction between the two formations being in this locality a line of fault. In no place, however, did this dyke pierce the Nullagine conglomerates, though some miles northward in the vicinity of the One-mile Creek, a narrow dyke of a similar character does rise to the level of the Nullagine Series, and can be followed across country north-west and south-east traversing in turn each individual bed.

The basal conglomerate is made up of rounded, ellipsoidal, or subangular fragments of the strata forming the older underlying series (the Mosquito Creek Beds). These often include pieces which may reach a length of three or four feet, but the bands containing the larger fragments are merely local. Photograph "B"

* *Loc. cit.*, p. 34.

PHOTO.: S. J. BECHER

A portion of the Auriferous Conglomerate, Nullagine.

shows a portion of this conglomerate at the entrance to one of the mine workings. The conglomerate consists chiefly of fragments of the existing conglomerates, cherts, grits, and shales; reef quartz, identical in character with that forming the auriferous deposits in the underlying strata, being a very common constituent. The pebbles are embedded in a matrix, which is principally sandy, though sometimes aluminous.

Some portions of the conglomerate contain flattened and striated pebbles [**5805**] of fine-grained sandstone and sandy shales, identical in character with the beds of the Mosquito Creek Series; to these striated pebbles a glacial origin has been assigned by the late Mr. S. J. Becher, and subsequently by Professor David. These pebbles, however, would, in the light of the evidence now available, seem to have had their striation induced previous to their taking part in the formation of the Nullagine Series. The beds upon which the series rest with a violent unconformability and to the denudation of which the pebbles owe their origin, having been subject to intense mechanical deformation, it would only be natural to find slickensided fragments and pebbles in the newer rocks. Earth movements have caused the Nullagine Beds to be thrown into a series of undulatory folds, well shown in the geological map and section, but the deformation thus engendered has not been of sufficient intensity to cause any striation of the component pebbles.

The conglomerates or consolidated shingles are of distinctly sedimentary origin, and owe their occurrence to the disintegration of pre-existing strata, which will be fully described on a later page. From the angularity of many of the pebbles, which make up the mass of the basal members of the series, it may be reasonably inferred, that the coast-line which furnished them was not far distant. No outliers of the series occur anywhere in the vicinity of the country embraced by the Geological Map of Nullagine. From this fact and the angularity of many of the conglomerate pebbles it may be inferred that the present boundary of the series approximately marks the original shore-line. The evidence available from a careful study of the district over which the series extends, shows that the surface upon which the beds were laid down was extremely irregular. This irregularity was particularly apparent in the neighbourhood in which the basal shingles have been mined. The auriferous strata occur through a thickness of about 300 feet of grits, sandstones, and conglomerate, forming the lowest portion of the series: those portions of the strata which have been proved to be gold-bearing are those which are largely impregnated with the oxides or sulphides of iron, and which lie between the fault north of Beaton's Creek and the greenstone dyke (possibly along a fault-line also) crossing the One-mile Creek in the vicinity of Mineral Lease 5L. As may be seen by the table below, the gold contents of the conglomerates are small, not amounting to more than at the rate of ·62 ozs. for the total tonnage crushed since mining first commenced.

Table showing the Yield of the Auriferous Conglomerates of the Nullagine Series.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
Previous to 1897	357·60	434·70	1·21
1897	246·00	228·00	·92
1898	893·00	1,001·20	1·12
1899	753·40	533·35	·70
1900	382·00	149·90	·31
1901	1,458·00	647·53	·44
1902	300·00	128·51	·42
1903	777·00	94·10	·12
1904	*Nil*	*Nil*	...
Total	**5,167·00**	**3,217·29**	**·62**

Igneous Rocks associated with the Series.

From the geological maps and the descriptions given in this and Bulletin 15, it will be seen that a great series of bedded lavas, ashes, and agglomerates form an integral, and no small, portion of the series as developed in different portions of Pilbara Goldfield.

Wherever these beds have been examined it has been invariably found that they consist of acidic lavas, the composition of some of these [**5392, 5404, 5384**] which may be regarded as typical of the series have already been published in Bulletin 15 and need not be repeated.

The greater mass of the rocks consist of separate lava-flows, each of no very great thickness. Some of the lavas are distinctly amygdaloidal, the cavities being filled with chalcedony.

Some of the finer-grained ashy beds [**5796**] differ very little in general appearance from many of the banded lavas, with which they are associated, but their distinctly fragmental character can readily be made out by the microscope, and in some cases with the aid of a pocket lens.

So far no evidence has been obtained which would throw any light upon the sources from which the lavas emanated.

In the neighbourhood of Coppin's Gap, the volcanic rocks of the Nullagine Beds are represented by coarse agglomerate, dipping at angles of about 20 to 30 degrees to the east, and passing beneath the sedimentary rocks of the series. Associated with these are beds of greenish grey lava. The sedimentary rocks of the series which occur at a somewhat higher horizon consist of coarse conglomerate and fine-grained sandstone. The hills of conglomerate rise to considerable heights above the surrounding plains, which in this particular locality are underlaid by granitic gneiss and allied rocks.

On the Coongan River, some distance below the township of Marble Bar, a mass of volcanic agglomerate forms a very conspicuous irregular-shaped hill, which presented every appearance of being the focus from which the surrounding lavas emanated.

There are several acidic dykes visible in different portions of the district, which may possibly represent another phase of that volcanic activity which was rife.

In the neighbourhood of the townsite of Nullagine, a mass of quartz felsite [5798] was met with in the well on W.R. 2L. This well has been carried down to a vertical depth of 108 feet, through quartz felsite the whole way. This rock, the position of which is shown on the map of the Nullagine Conglomerates Gold Mines forming Plate II., makes its appearance on the western bank of the creek, and rises to about the level of the floor of the battery site, where it seems to have diffused itself through a portion of the coarse auriferous conglomerate forming the base of the formation in this locality. The quartz felsite is very much decomposed, the alteration extending as far down as the bottom of the well, which is the deepest point at which it has been pierced. Examined under the microscope, the rock is found to consist of quartz and plagioclase, set in a partially devitrified matrix.

Age.

The recognition of the position of the Nullagine Beds in the stratigraphical succession is a point of considerable importance; the absence of fossils throughout the series, wherever it has yet been studied, however, renders correlation extremely difficult.

The earliest investigator of the district, Mr. H. P. Woodward,* assigned a Devonian Age to the series, though the evidence does not seem to be conclusive. The next observer, Mr. S. J. Becher, writes that of "the age and origin of these interesting Nullagine Beds nothing definite is known." †

Professor David infers that the beds are "probably of older Palæozoic Age (? pre-Cambrian) and should well repay further investigation." ‡

The limestones of the series having yielded no fossils, petrographical resemblance seems to be the only method by which any clue can, in the present state of our knowledge of the series, be arrived at with respect to its age.

In a previous report § the difficulty of correlating the Nullagine Beds with any of the formations described in the official publications on the geology of Western Australia was fully set out, and

* Annual Report of the Government Geologist for the Year 1890. Perth: By Authority, 1891, pp. 25 and 26.

† The Nullagine District, Pilbara Goldfield, Western Australia. Trans. Inst. Mining Engineers (Newcastle-on-Tyne), 1898. Vol. 16, Pt. I, pp. 44-52.

‡ Report of the Glacial Committee. Austral. Assoc. for the Adv. Sci. Vol. 9, 1902, p. 201.

§ A. Gibb Maitland. Preliminary Report on the Geological Features and Mineral Resources of the Pilbara Goldfields. Bull. No. 15. Perth: By Authority, 1904, p. 10.

the lithological resemblance to the quartzites, etc., of the King Leopold Range, in Kimberley, was emphasised. If this petrographical resemblance should prove to possess greater significance than at present appears, the Cambrian Age of the Nullagine Series would seem to have strong claims for consideration.

The Nullagine Beds have a very wide distribution in the North-West Division, and the Volcanic Series would seem to occupy a large area of country in the southern portion of the district. It may be noted that, in a bore put down by the Government at Onslow, near the mouth of the Ashburton River, to a depth of 1,729 feet, there was passed through a thin bed of a volcanic rock ("basalt" of the bore journal) identical in its characters with some of those igneous rocks forming part of the Nullagine Beds as developed elsewhere. It may thus be that these strata were pierced in the lower portion of the Onslow bore-hole.

Undoubted Permo-Carboniferous fossiliferous rocks are known to occupy a large area of country in the watersheds of the Gascoyne, the Minilya, and the Lyndon Rivers; hence an examination of the (geologically unknown) country lying between Onslow and the Lyndon River should afford some valuable information as to the mutual relations of the Permo-Carboniferous and the Nullagine Beds; hence it is from this district that the most important clue to the age of the Nullagine Series may be ultimately hoped for.

Mosquito Creek Beds.

The Mosquito Creek Beds, which underlie the strata of the Nullagine Series, comprise one of the oldest of the sedimentary formations as developed in Pilbara. The formation is abundantly represented, and occupies the surface of a very large area of country. The series, which consists of grits, shales, and fine conglomerates, takes its name from the district of Mosquito Creek, 24 miles due east of Nullagine, where these beds were first noticed.*

In that report attention was directed to the difficulty of separating the schistose rocks, which make up a large portion of the district, from these sedimentary rocks, and further observations have only served to emphasise that difficulty. As will be noted in the description of the geology of the Warrawoona field, which is made up of a mass of sedimentary strata, and associated igneous rocks, converted into crystalline schists, by metamorphic agencies operating on a regional scale, there seems good reason to believe that in the Mosquito Creek district the same conditions prevail.

The old 40-mile road from Mosquito Creek to Sandy and Middle Creeks follows an open longitudinal valley occupying the summit of a very broad anticlinal fold, which forms a very important structural feature in the district. It is upon the northern

* Preliminary Report on the Geological Features and Mineral Resources of the Pilbara Goldfield. A. Gibb Maitland. Bull. 15, Perth: By Authority, 1904. p. 78.

and southern flanks of this arch that all the auriferous quartz reefs of the Nullagine-Mosquito and Middle Creek zones occur.

A traverse from Nullagine township, south-eastward for about six miles to the cairn G. 16, on the summit of South Dromedary,* discloses a succession of highly inclined grits, sandstones, and shales with quartz veins. The whole series which forms the low ground underlies to the westward.

The two hills, the North and South Dromedary, which form the most conspicuous features in the landscape, rising as they do to a considerable elevation above the general level of the surrounding country, expose what appears to be the base of the Mosquito Creek Series.

The South Dromedary forms a ridge which has a general trend of north 50 degrees east, and a length of about half-a-mile. It is made up of vertical beds of conglomerate of considerable thickness. The conglomerate is very much cleaved, and the cleavage planes are seen to cut clean through the centre of many of the quartz and other pebbles. It may be noticed that the conglomerate contains numerous pebbles of laminated quartzite (chert), belts of which form such a conspicuous feature in other portions of the district, and are described in the previous report (Bulletin 15).

About two miles and a-half to the south-east of Quartz Claim 32* is a cairn, forming the summit of a tortuous ridge of laminated quartzite (chert). This quartzite underlies at an angle of about 40 degrees to the west, and with an average strike of north 70 degrees east. A few feet to the west of this is a remarkably conspicuous vein of quartz of considerable horizontal extent. From the position of this laminated quartzite, it would appear as though the beds in which it is enclosed belong to an older formation than that which comprises the strata of the North and South Dromedaries.

Between this hill and the South Dromedary (G. 16), sandy and micaceous beds (? sandstones or grits) of the Mosquito Creek type prevail. These strata are traversed by numerous quartz veins, lying parallel to the planes of bedding (? cleavage).

Farther to the eastward, a normal granite makes its appearance. This granite, which is clearly intrusive into the strata just described, is traversed by pegmatite veins which have, when viewed on the whole, a general strike of north 80 degrees east. In addition to the pegmatite veins, the granite is also seamed with an approximately parallel series of quartz reefs, which may merely represent another phase of the pegmatitic intrusions.

No estimate in the present condition of our knowledge of even the approximate thickness of the Mosquito Creek Series can be made, though the apparent enormous thickness of the formation may, in all probability, be due to the repetition of the beds by folding.

* *Vide* Mines Department Lithograph, L 76.

No trace of fossils having been met with anywhere in the series, so far as it has been examined, any definite data as to the age of Mosquito Creek beds is unavailable.

Observations, fully set out on an earlier page, demonstrate that they lie unconformably beneath the Nullagine Beds, and as in certain portions of the district the Mosquito Creek Series have been subjected to more or less intense dynamic metamorphism, a considerable period must have elapsed between the deposition of the two series.

The Mosquito Creek Beds are of economic importance, by reason of the fact that they form the matrices of the numerous auriferous quartz reefs which outcrop along a belt of about 24 miles in length, and have been more or less perfunctorily worked. A full description of the reefs occurring in the Mosquito, Sandy, and Middle Creek districts has already been given in Bulletin No. 15, pp. 78-101, and need not be repeated. In this report, particulars will only be given (under the heading of Economic Geology) of those reefs, etc., embraced within the area covered by the Geological Map of Nullagine (Plate I.), and to which no previous reference has been made.

As may be seen by a reference to the table below, the gold contents of the reefs are high, having an average of nearly 3ozs. for every ton of stone mined and milled, though the actual quantity of ore raised has, up to the present time, been very small.

Table showing the Yield of the Auriferous Quartz Reefs of the Mosquito Creek Series.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
Previous to 1897	339·50	1,126·20	3·31
1897	151·00	450·95	2·98
1898	605·50	1,174·55	1·94
1899	12·70	79·60	6·27
1900	101·00	478·90	4·74
1901	28·25	187·10	6·62
1902	*Nil*	*Nil*	...
1903	*Nil*	*Nil*	...
1904	*Nil*	*Nil*	...
Total	1,237·95	3,497·30	2·82

Greenstone Dykes.

Apart from the igneous rocks which form an integral portion of the Nullagine Series, the greenstone dykes make a conspicuous feature of the country in the more immediate vicinity of Nullagine.

Lying to the west of the township of Nullagine, and distant about two miles, is a very prominent greenstone [5799] dyke, which

attains its greatest development along the eastern bank of Kadjebut Creek. The summit of this dyke is formed of a very rocky ridge, made up of large rounded and subangular blocks of greenstone, producing in places a surface of indescribable roughness. This dyke has a general north-east and south-west strike, and extends some miles in a northerly direction far beyond the limits embraced by the Geological map. It has a width of about 1,500 feet, and wherever seen in section the dyke has a decided tendency towards verticality. So far as could be seen, there appeared to be very little, if any, appreciable alteration of the enclosing rocks on either wall of the dyke. In two places along its course the dyke sends out tongues into the surrounding rocks. It is quite possible that there may be some underground connection between the main dyke and those two smaller ones which occupy a portion of the surface to the east of the Great Eastern line of reef. These two dykes, the position of which is shown on the Geological map, have a horizontal extent of about 15 and 50 chains respectively.

This large, or what may be called main, dyke is nowhere seen to pierce any other strata than those of the Mosquito Creek Series.

At a point about 20 to 30 chains to the west of this larger dyke is another approximately parallel one, first making its appearance between the Victory and the Day Dawn groups of leases, and traversing the country to the northward in the vicinity of M.A. 4 L until it disappears beneath the alluvium of the Nullagine River. Although it rises to a considerable height above the general level of the surrounding plain and forms a prominent surface feature, it nowhere exceeds a width of two chains. This dyke also does not pierce any other strata than those belonging to the Mosquito Creek Series.

On the north side of the Nullagine River, and in the vicinity of the One-mile Creek, is another greenstone [**5794**] dyke, trending generally north-west and south-east. It has been followed across country for a mile and a-half, and extends far beyond the limits of the map. This dyke, which traverses both the Mosquito Creek and the Nullagine series, does not make any very pronounced feature in the landscape, though it can be readily followed. Its width nowhere exceeds two chains in width, and when seen in section is vertical, or nearly so.

There seems very good reason for believing that this dyke may be the prolongation of that disappearing beneath the alluvium of the Nullagine River, in the vicinity of M.A. 4L. The course of the dyke north of the One-mile Creek is approximately parallel to that fault which lies to the north of Beaton's Creek, and it is quite conceivable that the One-mile Creek dyke may occur along a line of fracture also, although no obvious dislocation of the strata is apparent. Whatever may be the exact age of these dykes it is quite clear that the one last described is newer than the series of strata it penetrates.

The rock [5799] of which this dyke is formed is of medium grained, crystalline structure. The only minerals which are readily recognisable with the aid of a lens are felspar, pyroxene, and occasionally an iron ore.

Under the microscope, relatively large proportions of crystals of augite, some of which are changed into a pale green dichroic mineral, stand out very prominently. All the felspars, which seem to be plagioclase, and make up the greater part by volume of the rock, present in all cases that turbid, mealy aspect due to alteration. The iron ore seems to be either magnetite or ilmenite, though pyrites is present in some portions.

The rock [5794] forming the largest and most conspicuous dyke in the field is a very fresh, fairly cross-grained rock, consisting of pyroxene, with a metalloid lustre, together with a white, and in some cases, almost colourless felspar, plagioclase. The felspar forms by far the larger proportion of the rock, and, when examined under the microscope, is found to be very much altered. A little quartz can be detected in some portions of the slide. The specific gravity of the rock is 2·82.

An analysis of a fresh, unweathered specimen [5794] made in the Survey Laboratory, showed its chemical composition to be —

Silica, SiO_2	54·92
Alumina, Al_2O_3	14·27
Ferric Oxide, Fe_2O_3	1·28
Ferrous Oxide, FeO	5·25
Magnesia, MgO	10·32
Lime, CaO	6·42
Soda, Na_2O	2·50
Potash, K_2O	·64
Combined Water, H_2O	2·96
Hygroscopic Water, H_2O	·12
Carbonic Anhydride, CO_2	·38
Titanic Oxide, TiO_2	·90
Iron, Fe } FeS_2	·10
Sulphur, S }	·12
Maganese Protoxide, MnO...	trace.
	100·18

This apparently differs but little from that last described [5799], except in the coarseness of grain.

So far as any observations have at present been carried in the district, these dykes appear to have no apparent connection with any visible deep-seated rock of similar composition.

Economic Geology.

The Nullagine District comprises three distinct types of auriferous deposits, viz.:—Alluvial and other Superficial Deposits; Quartz Reefs; and Auriferous Conglomerates. The respective yields of each is shown in the table below.

Synoptical Table showing the Total Gold Production of Nullagine up to the end of 1904.

Nature of Deposit.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
Alluvium and Superficial	...	3,670·02	...
Quartz Reefs	1,237·95	3,497·30	2·82
Auriferous Conglomerates	5,167·00	3,217·29	·62
Total	**6,404·95**	***6,714·59**	**1·04**

* This total does not include that of the alluvial gold.

From this table it will be noted that, in so far as the number of ounces is concerned, the alluvial and superficial deposits have proved to be the most important, whilst the yield from the quartz reefs has exceeded that from the auriferous conglomerates by 108·84 ounces, although the average grade of the quartz proves to be more than four times greater.

Considering the number of years this mining centre has been in existence, it must be candidly admitted that the gold yield is disappointing.

In addition to the above totals, 1,638·50oz. of gold have been obtain from the cyaniding of nearly 3,000 tons of tailings. It is, however, not possible to separate the yield of the tailings from each centre, but as they were all cyanided at Lambert's Treatment Works, M.A. 4L, it is probable that most of the ore was obtained from the more immediate vicinity of Nullagine itself.

Table showing the Yield of the Tailings Cyanided at Lambert's Treatment Works, M.A. 4L.

Year.	Tons treated.	Gold therefrom.	Rate per ton.
	tons	ozs.	ozs.
1902	1,960·00	1,259·05	·64
1903	840·00	379·45	·45
Total	**2,800·00**	**1,638·50**	**·58**

This return thus brings the total gold yield of Nullagine up to 12,023·11ozs., as recorded at the close of 1904.

Alluvium and Superficial Deposits.

The alluvium and the other superficial deposits call for no special notice, beyond the fact that there seems good reason to believe that no small portion of the "alluvial" gold was obtained from the numerous creeks draining that portion of the escarpment of the Nullagine Series lying between Beaton's and the One-mile

Creeks. Over this area, which is that occupied by the ferruginous basal conglomerates, skilful dryblowers are still able to obtain a certain quantity of gold, derived, in all probability from the residual concentration of the gold set free from the conglomerate. Owing to the circumstance that a considerable proportion of the gold so obtained is probably never officially reported, the actual yield from this source cannot be set out in figures.

Quartz Reefs.

Quartz reefs occur in great abundance in the country lying to the westward of the Nullagine River. These reefs outcrop over a belt about four miles in length, which emerges from beneath the beds of the Nullagine Series near Suburban Water Right 5L, and extends in a general north-easterly direction across the whole area of the geological map. So far as any observations have been made it seems that the productive area of the Mosquito Creek Beds, as developed in the more immediate vicinity of Nullagine, consists of a broad belt about a mile in width, with a general strike of north-east and south-west, which latter coincides with the general trend of the series.

The position of most of the quartz reefs has been accurately laid down upon the Geological Sketch Map of Nullagine (Plate I.). They exhibit, when viewed on the whole, a general parallelism, which is coincident with the plane of bedding of the enclosing rocks. The reefs invariably occur along the bedding planes, or, at any rate, cut them at a very low angle. Few of them attain any very great horizontal extent, nor, so far as could be judged by a careful inspection of the surface, did they reach, as a whole, any great thickness.

The quartz of which the reefs of Nullagine are composed is generally of a whitish colour, contains little, if any, pyrites, and of such a character as render it readily amenable to battery amalgamation and cyanidation.

Several of the reefs have been opened up and worked to relatively shallow depths.

The Mines.

No work of any description was being carried on at the date of my visit to the district, and none of the mines were accessible.

I have extracted a good deal of information from the manuscript reports of the different Inspectors of Mines, and the following notes may serve the purpose of giving some idea of the state of development of the mines and other cognate points at the time these officers visited the district. These notes, however, make no pretensions to being more than a mere general account It is much to be regretted that no better official record has been kept of the statement of development of the district, a condition of affairs which virtually obtains over the whole of such portions of the Pilbara Field as have yet been visited.

For convenience of description the various properties are dealt with in geographical order, commencing at the north-easternmost end of the field. The location of each of the properties described will be found on the Geological Sketch Map of Nullagine. (Plate I.)

Fisher's Reward, G.M.L. 65L.—This, the most northerly of the leases in the country to the east of the Nullagine River, is traversed by two small parallel quartz reefs of no very great horizontal extent. A very little desultory work has been done upon the property, which was held for a period of about four months during a portion of the years 1896 and 1897. A few tons of quartz were raised and crushed in 1897; the official figures show that 20 tons of ore crushed yielded 56·6 ounces of gold, or at the average rate of 2·83ozs. per ton.

Try Again, 66L.—This lease adjoins that last described, on the south, and was at one period of its history known as the Turkey Mary. There are two distinct vertical reefs on the property, the easternmost having the greatest horizontal extent. The lease appears to have been held for a period of about five months only, during a portion of the years 1896 and 1897. Two small shafts have been sunk, but although the reef proved to be small, it is stated to have been rich. There are no crushings recorded from the property.

Promise, G.M.L. 331 (25L).—This six-acre lease lies some little distance to the west of the Try Again and about 35 chains to the east of the Nullagine River.

The property appears to have been held for about 18 months, having been surrendered in July, 1897.

There are two short reefs outcropping near the north-western boundary of the property, and three others, the position of which is shown on the plan, adjoining. A vertical shaft, 20 feet in depth, was put down, but the Inspector of Mines' report states that there was no reef exposed in it. A second shaft, 25 feet vertical, was continued on the underlay for 25 feet farther, in a south-easterly direction, on a small quartz vein; this, in the eastern shaft, the Inspector of Mines' report states, attained a thickness of two feet. There appears to be no record of any crushings from this property in the official statistics, unless such are included with those from sundry claims. The field note book, however, of the late Mr. S. J. Becher, at one time Inspector of Mines, contains the statement that "about 30 tons crushed over 90ozs., and that the first five tons went 10ozs. per ton." From this it would seem that some very rich ore must have been met with.

Sunrise, G.M.L. 58L (480).—This lease is situated in the triangular piece of ground, bounded by the Nullagine River, Kadjebut Creek, and the gabbro dyke, shown on the geological map. A fairly well-marked quartz vein outcrops for some distance along the eastern boundary of the lease; and has been opened out by means

of a shallow shaft. Little or nothing, however, can be seen at the present time. The lease was abandoned in 1897; there are no crushings from the lease in the official statistics, unless any such are included under the heading of the yield from sundry claims.

SUNRISE No. 1, G.M.L. 57L (429).—This property, which adjoins the Sunrise on the north-east, appears to have been taken up in September, 1896, and abandoned in the month of January of the following year. A small quartz reef, probably a continuation of the Sunrise, occupies a portion of the surface, near the south-eastern boundary of the property. The only work done on the property appears to have been raising the few tons of quartz which are shown in the official returns. These demonstrate that, previous to 1897, 28 tons of ore crushed yielded 14ozs. of gold, or at the rate of ·50ozs. per ton.

THE GREAT EASTERN GROUP of leases lie about a mile to the south of the Sunrise, and are situated on the eastern bank of Kadjebut Creek, almost due west of the Nullagine township.

GREAT EASTERN, G.M.L. 59L.—The Great Eastern Reef makes a very pronounced outcrop, forming as it does the highest point of a low, though conspicuous ridge, which rises some 15 or 20 feet above the level of the surrounding country. The general strike of the reef is north-easterly, and, as measured at the surface, has an underlie of 70 degrees to the south-west; from this it would seem that the reef is much steeper at the surface than underground. The country rock of both walls of the reef is slate; the reef measures about four feet in thickness, and the quartz is white, with ferruginous portions, due to the oxidation of pyrites. A fair quantity of stone from the outcrop had been raised to a depth of from 15 to 20 feet from the ground level. Mr. Inspector Gladstone's report mentions a vertical shaft 40 feet in depth, which had been continued on the underlay for a distance of 80 feet. At 30 feet in the shaft, a level is referred to 35 and 40 feet in length, driven respectively north-east and south-west, whilst at 90 feet a north-easterly level had been driven for a horizontal distance of 40 feet. There is no information in Mr. Gladstone's report as to the dimensions or character of the reef in the mine, and the workings were inaccessible to me.

The following figures give the yield of the reef in so far as it may be gained from official data:—

Table showing the Yield of the Great Eastern Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
Previous to 1897	20·00	33·80	1·69
1898	150·00	168·95	1·12
Total	**170·00**	**202·75**	**1·19**

Enterprise, G.M.L. 76L.—This is an isolated lease about three-quarters of a mile to the north-west of the Great Eastern Group. It embraces a part of the old Union Jack Lease 40L. A fairly well-defined reef, which can be followed more or less interruptedly across the surface to the south-west for a distance of 2,500 feet, traverses the lease. Several shafts have been sunk to depths of which there is no information. Water is said to have been met with in two of them at 35 feet. These shafts have been utilised as a source of water for the Battery and Cyanide Plant at one time erected on M.A. 4L, which embraces part of the lease. There have been no crushings recorded from the property, unless they are included in the yield from sundry claims.

In the vicinity of this lease there are several other parallel reefs of smaller size, upon which a little work has been done at one time or another, but there are no particulars available in respect to the yield of any of them.

About 800 feet to the south-west of the Enterprise Reef is another parallel vein, which can be followed more or less interruptedly across the surface for about 3,000 feet, and it is quite possible that the reef, disappearing beneath the alluvial flat of the Nullagine River to the north-west of the Day Dawn Group, may represent an extension of it.

Scottish Chief, G.M.L. 64L.—This is an old abandoned twelve-acre lease, adjacent to the Day Dawn Group on the north. There are three well-defined though small reefs traversing the property, and upon two of them, the north and south reefs, shafts have been sunk; these, however, are inaccessible, hence no particulars are available. There do not appear to have been any crushings recorded from the property.

Day Dawn, G.M.L. 278 (17L).—Upon this property there are several well-defined parallel reefs outcropping. The reefs have an average strike of north-east, with an underlie of about 40 degrees to the south-east. The main reef, viz., that upon which the bulk of the work has been carried out, averaged on the surface about two feet in thickness. It consisted of a white, and, in places, very ferruginous quartz, and is stated by Mr. Inspector Becher to have contained very coarse gold. Mr. Becher notes that the reef had been opened by means of an underlay shaft 45 feet in depth, which was also connected with the surface by a vertical shaft of 20 feet. A little driving had been done along the reef to the south-east. At a later date, 1898, Mr. Inspector Gladstone notes that the shaft had been carried down to a depth of 69 feet, and that driving to 252 feet had been carried out. No particulars as to the nature of the reef underground is to be found in the reports of the inspectors, which is much to be regretted, as the workings are at the present time inaccessible. Only 266 tons of stone have been crushed during the three and a-half years the lease was in existence, particulars of which are shown in the table below. In addition to these figures, Mr. Becher notes that 18 tons of *débris*, with which the surface of the lease was covered, yielded 18oz. of gold.

Table showing the Yield of the Day Dawn Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
Previous to 1897	174·00	600·00	3·45
1898	92·00	102·70	1·11
Total	**266·00**	**702·70**	**2·64**

Day Dawn No. 1 South, G.M.L. 388 (43L).—A twelve-acre lease, adjoining that previously described, which was held for a little over twelve months and abandoned in December, 1897. Two short reefs, one of which may represent the extension of the Day Dawn, occupy a portion of the south-western corner of the ground. Very little work appears to have been done upon the property, and there is no record of any crushings from it.

Day Dawn North, G.M.L. 418 (52L).—No work of any moment appears to have been done upon this lease.

The Victory Group of leases, only one of which, however, is now extant, occupies an extent of country about a mile in length, over which several small quartz veins outcrop.

Victory, G.M.L. 134L.—This lease embraces the greater portion of what was originally the Victory East Extended, G.M.L. 56L (424 or 99L), Walter's Folly; the original Victory, G.M.L. 383 (42L), to which it is desirable the name should be still applied, is situated some little distance southwards along the line. Five shafts have been sunk upon the lease, and, judging by the condition of the dumps, a good deal of work must have been done. None of the shafts, however, were accessible to me, and there appear to have been no plans of the workings. Mr. Inspector Gladstone mentions two underlay shafts, each 135 feet deep, and connected with drives from which 172 tons of ore had been crushed for a return of 625ozs. of gold, and a main shaft, which at the date of his visit had been carried down 70 feet. According to the official records of the mine, given in the table below, the gold yield seems to have been high.

Table showing the Yield of the Victory (East Extended) Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
Previous to 1897	12·50	50·90	4·07
1897	42·00	195·25	4·65
1898	116·00	388·30	3·34
1899	*Nil*	*Nil*	...
1900	89·00	414·35	4·65
1901	25·50	181·00	7·09
Total	**285·00**	**1,229·80**	**4·31**

VICTORY No. 1 EAST, G.M.L. 53L (419).—Known later as the New Victory Extended, G.M.L. 70. The reef, traversing the adjoining property previously described, extends more or less interruptedly along the south-eastern boundary of the lease. It has been opened up by an inaccessible vertical shaft, of a depth of which there appears to be no record. There are no returns of any crushings from this lease.

VICTORY, G.M.L. 383 (42L).—What is known as the main Victory reef traverses the south-eastern boundary of the property, though it makes very little show on the surface. An inaccessible underlay shaft had been carried down, according to Mr. Becher's notes, to a depth of 81 feet, on a quartz reef underlying at an angle of 60 degrees, and attaining a thickness of from three to four feet. The walls of the reef, as described by Mr. Becher, are "perfect," and are made up of a soft, fine-grained, solid, white sandy shale, which is stated to harden on exposure. The quartz is very highly coloured by oxide of iron, and, according to Mr. Becher, showed gold freely at the bottom. A vertical shaft was being put down at a spot 50 feet distant from the mouth of the underlie shaft, designed to intersect the main reef at about 80 or 90 feet, but there is no official record as to whether this was accomplished. At the time Mr. Becher was at work in the Nullagine district, a small crushing of 25 tons of stone from the reef in the inclined shaft is reported to have yielded 130ozs. of gold, or at the rate of 5·20ozs. per ton of ore crushed. A small trial crushing of a few tons by former holders of the property yielded gold at the rate of 3ozs. per ton. The official yield of this lease is given in the table below.

Table showing the Yield of the Victory Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
Previous to 1897	75·00	337·50	4·50
1897	46·00	83·60	1·81
Total	**121·00**	**421·10**	**3·48**

VICTORY EXTENDED, G.M.L. 51L (417).—A small six-acre lease adjoining G.M.L. 383 on the south-east, and traversed by a reef which was thought to be the southern extension of the Victory. So far as can be judged, however, it seems probable that it is a parallel reef. An underlie shaft had been carried down on the reef to a depth of 30 feet, when it cut out. The shaft, however, was carried down another 20 feet, at which point a crosscut had been put in 20 feet to the north, with the object of testing the country, and another crosscut to the south had been commenced at the date of Mr. Becher's visit. His notes, however, give no par-

ticulars as to whether the reef had been picked up below the depth at which it cut out. In 1897 22 tons of ore are officially recorded as yielding 63ozs. of gold, or at the rate of 2·86ozs. per ton.

MARQUIS, G.M.L. 62L.—A disused and inaccessible shaft is situated at a point 13 feet from the north-east angle of the lease, and is traversed by a small reef parallel to that in the adjoining property on the north. About 100 feet south from the north-east angle is a well-defined reef, shown on the geological map, underlying at a high angle to the north-west, but no work has been done upon it.

There are one or two other abandoned leases and quartz claims in the vicinity of Kadjebut Creek to the west of the South Dromedary G. 16. The position of these properties is shown on the 40 chain lithograph L 76, issued by the Department of Mines.

GOLDEN EAGLE, G.M.L. 77L (formerly Alexandra, G.M.L. 71L).—A great deal of desultory work has been carried out upon what were evidently distinct veins, but all the workings are inaccessible at the present time. According to the official records, small crushings from this lease took place annually from 1897 to 1901, but although the total quantity of gold, under 500ozs., so obtained was small, the average per ton was over four and a-half ounces. There would thus seem to have been some very rich shoots met with in the course of the work.

Table showing the Yield of the Golden Eagle Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1897	21·00	52·50	2·50
1898	57·50	290·20	5·04
1899	12·70	79·60	6·26
1900	12·00	64·55	5·38
1901	2·75	6·10	2·22
Total	**105·95**	**492·95**	**4·65**

REWARD CLAIM, 33L.—A small abandoned lease on the eastern bank of Kadjebut Creek, and lying about three-quarters of a mile to the south-east of the Golden Eagle. An east and west vertical reef has been opened up by a shaft which is inaccessible at the present time, hence no information as to the character and behaviour of the reef underground can be obtained. There appear to be no records of any crushings from this property, unless they are included under the heading of the yield from sundry claims.

The following synoptical table gives the total gold yield of the reefs of Nullagine, in so far as such may be obtained from official statistics:—

Synoptical Table showing the Yield of the Nullagine Reefs up to the end of 1904.

Name of Reef.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
Day Dawn	266·00	702·70	2·64
Fisher's Reward	20·00	56·60	2·83
Golden Eagle	105·95	492·95	4·65
Great Eastern	170·00	202·75	1·19
Great Eastern Extended	190·00	224·40	1·18
Promise	30·00	90·00	3·00
Sunrise No. 1	28·00	14·00	·50
Victory	121·00	421·10	3·48
Victory East Extended ...	285·00	1,229·80	4·31
Victory Extended ...	22·00	63·00	2·86
Total	**1,237·95**	**3,497·30**	**2·82**

Auriferous Conglomerates.

Mining operations have, up to the present, been confined exclusively to the outcrop of the conglomerates and to very limited and shallow depths; but work, however, has been carried sufficiently far to enable some idea of the conditions governing the gold deposition being ascertained. The conclusions to be drawn from these data may have some influence upon the practical development of the field. The gold contents of the conglomerate are small, not amounting to more than 3,217·29ozs. derived from the milling of 5,167 tons of ore, or at the rate of ·62oz. per ton.

Of the different areas in which the conglomerate has been worked, the largest quantity of gold, so far as may be judged by the official figures, appears to have been obtained from the workings now embraced by the Grant's Hill Lease 122L. (*vide* the plan of the Nullagine Conglomerate Gold Mines, Plate II.) The returns from this demonstrate that 3,433 tons of ore yielded 1,780·24ozs. of gold, or at the rate of ·52oz. per ton.

The auriferous conglomerate, which has already been shown to be of sedimentary origin, is made up of rounded and subangular fragments of the strata identical in character with that forming the underlying Mosquito Creek Series. Certain portions of the conglomerate are marked by the presence of abundant iron pyrites, and its oxidation products [**5802**, **5806**]. It is, however, in the oxidised zone of the conglomerate that any mining has, up to the present, been carried on.

In 1897, samples of the auriferous conglomerate were examined in the Survey Laboratory and have been thus described:—

"A specimen [190] typical of the finer-grained portions of the rock in its upper decomposed portions. It consists of subangular fragments of quartz, ironstone and shale, cemented together by ironstained kaolin, containing numerous cuboidal cavities at one time filled by pyrites crystals, as shown by the numerous pseudomorphs of limonite contained by them. . . . . It assays 1oz. 6dwts. of gold. . . . . A similar but less ferruginous variety, [191], showed no cavities vacated by pyrites, and is much coarser in grain, some of the fragments of quartz being 3 inches in length; it assays 2ozs. 1dwt. of gold per ton."*

Another variety [192] made up of large pieces of felstone, with smaller fragments of quartz embedded in a kaolinic matrix, assayed 10dwts. of fine gold and 5ozs. 4dwts. of coarse gold per ton.

A noteworthy feature in the conglomerate is the occurrence of pyrites and its oxidised representatives. In the unoxidised portions [3718, 5801, 5802] the pyrites occurs both as crystals, grains, and rounded or pebble-like forms. A photograph of a small but characteristic form [5802] is shown in Photograph "C." Some of the pyrites nodules measure an eighth of an inch in diameter, though from the size of some of the hematite pebbles there must be some which reach as much as three-quarters of an inch in diameter. A photograph of one of these hematite pebbles [5801] forms Photograph "D."

Considerable interest attaches to the occurrence of these rounded pebbles and pellets of pyrites and hematite in that they have been held to indicate a detrital character as well as ascribing a similar origin to the gold, which seems invariably to be associated with the occurrence of the ores of iron in the conglomerate.

A radiate fibrous structure can be detected in some of the oxidised conglomerates [5801] when the hematite pebbles exhibit fractured surfaces.

In some portions of the conglomerate [190] these hematite fragments make up fully one-half of the rock. The gold [1509, 3167] in the conglomerate almost invariably occurs in or lining the sides of these cavities which have been left by the removal of the iron ore. All its characters point to the gold having been left where it is now found by the oxidation of the pyrites.

The evidence, so far as it goes, respecting the origin of the gold in the Nullagine conglomerate seems to indicate that it is a secondary, and not an original constituent, and further that the primary source of the gold is the quartz reefs which occur in the underlying formation.

From the known occurrence of auriferous quartz reefs, which furnished no small portion of the pebbles of certain portions of the

* Annual Progress Report of the Geological Survey for the Year 1897. Perth: By Authority: 1898, p. 48.

PHOTO.: E. S. SIMPSON.

Rounded Pyrites Pebble in Conglomerate, Nullagine Series.

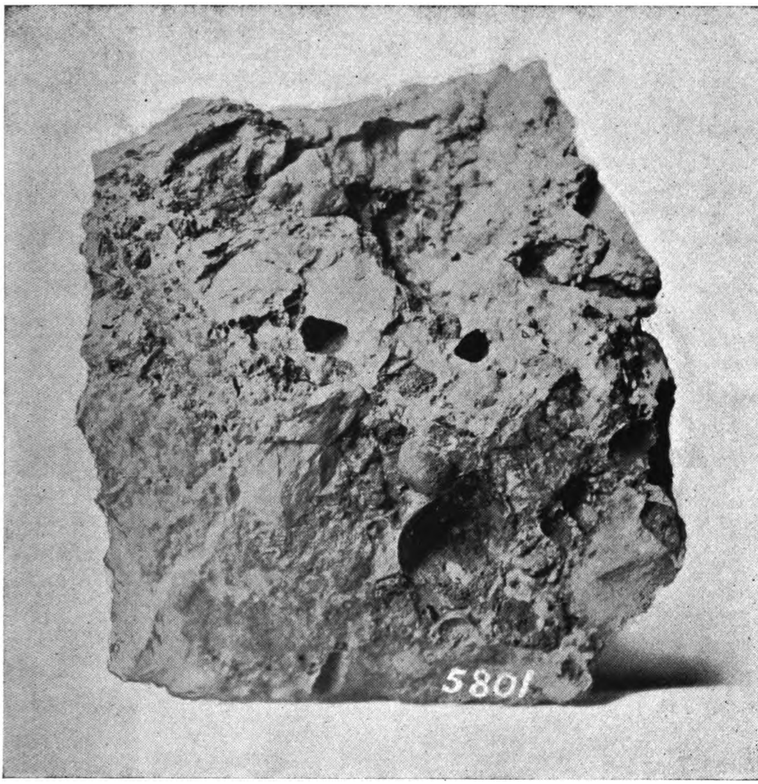


PHOTO.: E. S. SIMPSON.

Rounded Hematite Pebbles in Conglomerate, Nullagine Series.

deposit, it is of course quite conceivable that a certain amount of detrital gold forms part of the conglomerate, but there are obviously no means of ascertaining what is the proportion of primary to secondary gold.

There seems, however, good reasons for believing that by far the bulk of the gold, together with the pyrites, was introduced by solutions percolating down the most porous portions of the conglomerate, this condition being facilitated by the downward inclination of the bed-rock, and, possibly, accentuated in part by the folding which the strata have undergone.

The intrusion of felsite into the lower portion of the conglomerate (Plate II.), and the volcanic phenomena of which it formed a part, may possibly have resulted in the formation and circulation of the mineralising solutions, and also the deposition of the gold.

There is no evidence that the diabase dyke and the fault (Plate I.) have had any beneficial effect upon the gold contents of the conglomerate, but the fact remains that it is only in that portion of the formation lying between these two lines of fracture that any gold has hitherto been found. It is also noteworthy that the base of the Nullagine Series has only proved auriferous in those places where it lies upon that portion of the underlying formation which carries auriferous deposits. It may be noted, also, that over that portion of the formation from which the conglomerate crushings have been obtained numerous dryblowers have been at work for a number of years, and have obtained a considerable quantity of gold, of which the published figures afford no clue, for much of it in the early days was probably never officially reported.

Probably one-half of the alluvial gold from Nullagine, shown in the figures on page 16, may be legitimately claimed as having been derived from the escarpment of the conglomerate.

The high assays [**190, 191, 192**] alluded to are the exception, and merely indicate the occurrence of unusually rich shoots in portions of the conglomerate.

No attempt was made to sample any portion of the conglomerate workings, with the view of arriving at the value of the deposits, but six samples (which seemed to be characteristic of the type of deposit), collected during the course of the fieldwork, were assayed in the Departmental Laboratory, with the following results:—

[**5800**].—Grant's Hill Lease 122L. Oxidised Conglomerate in which the iron had been entirely leached out. Gold, 6dwts. 23grs. per ton.

[**5801**].—Grant's Hill Lease 122L. Oxidised Conglomerate, with abundant hematite kernels. Gold, 2dwts. 11grs. per ton.

[**5806**].—Dean's Hill, Mineral Reward Claim 6L. Oxidised Conglomerate with hematite kernels (some portions of this conglomerate show free gold). Gold, 4dwts. 2grs. per ton.

[**5802**].—Freak of Nature, G.M.L. 121L. Pyritous sulphide conglomerate. Gold *nil.*

[**5803**].—North-west of the Success, G.M.L. 119. Very slightly pyritous conglomerate. Gold *nil.*

[**5804**].—North-west of the Success, G.M.L. 119. Non-pyritous conglomerate. Gold *nil.*

To arrive at the value of the deposits, as can be readily understood, is an exceptionally difficult matter, but the figures of the output afford some idea of the yield of those isolated portions of the conglomerate which were deemed worth working.

The records of production of the conglomerates, given in the table on an earlier page (p. 26), seem to indicate a general decrease in the yield, the latest crushing of 777 tons returning gold at the rate of ·12oz. per ton.

Fluctuations in the gold yield per ton are, of course, only to be expected, but it cannot be said that the average of all the crushings recorded is any index to the value of the whole of the conglomerate series, if worked upon a large scale. It would probably prove to be a very low grade, and possibly so low as to render remunerative working, unless under the most favourable economic conditions, impossible.

The known occurrence of such an extensive formation as the Nullagine Series has proved, by mapping, to be and the fact that it has been shown to contain considerable quantities of gold in localities where the requisite and qualifying conditions for deposition obtain, would seem to encourage efforts in the direction of carefully prospecting other parts of the basal members of the series in the district.

Such prospecting should be a relatively easy task, seeing that it has already been shown that the auriferous portions of the conglomerate have invariably proved to be those which are the most ferruginous, hence the search for ironstained conglomerates near the base would seem to be the lines upon which such efforts should tend.

The Mines.

Grant's Hill, G.M.L. 122L.—A considerable amount of *bonâ fide* work has been done upon the western angle of the lease, as may be seen by an inspection of the plan of the Nullagine Conglomerates Gold Mines (Plate II.)

Fairly extensive workings on the south side of the tramline which connects with the battery have been carried on in a bed of coarse conglomerate, the exact thickness of which does not appear to have been determined. The conglomerate (or boulder bed) contains large boulders of flat-sided quartz, siliceous conglomerate, and other rocks occurring in the vicinity. This portion of the workings lies in the oxidised zone of the conglomerate which contains cellular portions from which iron pyrites has weathered out [**5800**]. This sample assayed in the departmental laboratory 6dwts. 23grs. of gold per ton.

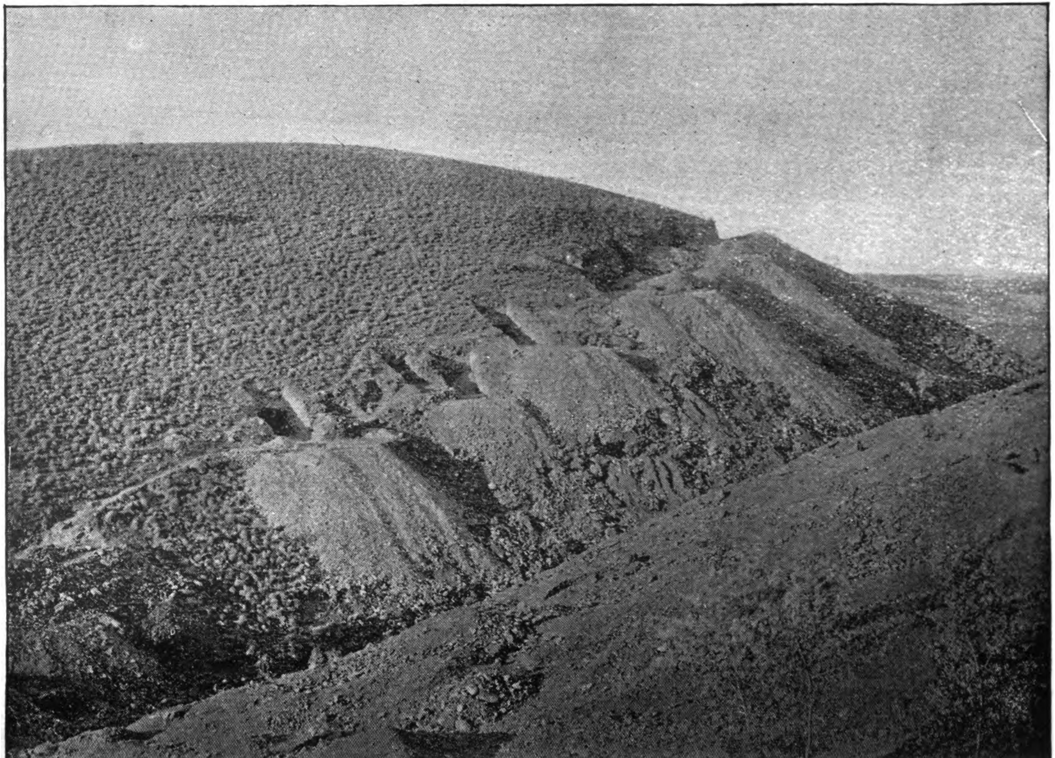


PHOTO.: S. J BECHER.

Workings on the Grant's Hill Conglomerate, Nullagine

The larger portions of the workings, however, occur on the southern slopes of Grant's Hill, which lies on the north side of the creek which drains the gully in a westerly direction. (Photograph "E.")

A good deal of ore must have been taken out at one time or the other, for the workings extend for some considerable distance round the slope of the hills. The larger portion of the work has been carried out on a bed of conglomerate, underlying generally west-north-west, rising gradually up and along the hillside at an angle of about 40 degrees, and as the plan (Plate II.) and statistics show, a good deal of ore must have been taken out.

A fault with a very small displacement occurs in one portion of the workings, and it appears to be parallel to the main fault shown on the geological and mining maps (Plates I. and II.)

A thickness of only from three to four feet of the conglomerate has been worked. So far as can be gathered from the official statistics, the returns from what is now Grant's Hill are set forth in the table :—

Table showing the Yield of the Grant's Hill Conglomerate.

Year.	Ore crushed.	Gold therefrom.	Rate per ton
	tons.	ozs.	ozs.
Previous to 1897	109·00	147·00	1·35
1897	*Nil.*	*Nil.*	—
1898	275·00	382·35	1·39
1899	462·00	343·25	·74
1900	152·00	70·50	·46
1901	1,358·00	614·53	·45
1902	300·00	128·51	·42
1903	777·00	94·10	·12
1904	*Nil.*	*Nil.*	—
Total	**3,433·00**	**1,780·24**	**·52**

To what may be called the Grant's Hill conglomerate should be added the small crushing of 85·40 tons, which yielded in 1899 40·70ozs. of gold, or at the rate of ·47oz. per ton, from what was originally known as the Trinity No. 1 South, G.M.L. 422, and subsequently Grant's Hill South, G.M.L. 68L.

This old twelve-acre lease adjoined the present Grant's Hill lease on its southern boundary, and apparently included the ground now occupied by the "Residence" shown on the plan of the Nullagine Conglomerates Gold Mines (Plate II.). The conglomerate from which the crushing was taken occupied the crown and the north-western slope of the hill lying to the east of the main fault. This hill formed a very rich field for dryblowers in the early days of Nulliagine.

This additional crushing brings the total return from the Grant's Hill conglomerates up to 1,820·94ozs., obtained from the milling of 3,518·40 tons of ore, or at the rate of ·51oz. per ton.

Freak of Nature, G.M.L. 121l.—What is now the Freak of Nature Lease includes the ground originally embraced by the Freak of Nature, G.M.L. 208, the Freak of Nature Extended, G.M.L. 21, and the Exchange, G.M.L. 18.

The most easterly working near the eastern angle of Grant's Hill was originally known as Neale's No. 3 Underlay. Work in this shaft had been confined to a bed of conglomerate, 3 feet in thickness, underlying to the north-west at angles varying from 18 to 20 degrees. The late Mr. Inspector Becher sampled this conglomerate, and reported the prospects to be "fair."

It would seem that this conglomerate is on the same horizon as that exploited in the adjoining Grant's Hill Lease.

The next working, on a slightly lower horizon, was known as Hewett's Shaft, and a little work was done upon a conglomerate from 2 feet 6 inches to 3 feet 6 inches in thickness; from this locality Mr. Becher also obtained "fair" prospects. This conglomerate appeared to be much more kaolinic than that in Neale's shaft.

Another shaft, shown upon the plan, had been put down upon a conglomerate, on a lower horizon, but no particulars respecting it are available.

There appears to be no record in the statistics of any crushings having been made on the old Exchange Lease; should any have been recorded they may be included in the yield from sundry claims, etc. It does not, however, appear from the conditions of the workings that any very large body of ore can have been taken out. From that portion of the present Freak of Nature Lease, which embraces the old Freak of Nature, G.M.L. 208 (1l), practically no work seems to have been done.

At a point on the northern bank of the main creek, near the north-eastern boundary of the lease, is a cliff of unoxidised pyritous conglomerate, which is distinctly banded.

A typical sample [5802] of this pyritous conglomerate, when assayed in the departmental laboratory, yielded, however, no trace of gold.

On the south-eastern portion of the lease, lying to the south of the pyritous conglomerate previously described, and in the ground originally embraced by the old 5-acre lease, Freak of Nature Extended, a big tunnel (Plate II.) has been put in, upon a boulder conglomerate. Judging by the present condition of the workings there seems to have been a good deal of work done, and a fairly large quantity of stone taken out. Mr. Becher's note-book indicates that the result of his sampling was that the prospects were "poor."

There are no official records of the yield of this portion of the property.

SUCCESS EXTENDED, G.M.L. 120L.—This 24-acre lease embraces part of the old Rejected, G.M.L. 414, Success, G.M.L. 352, and the Freak of Nature, G.M.L. 208. It is, however, only in the old Success and the Rejected that any mining work has been done.

The small patch lying between the 80 and 90 feet contours, in the northern portion of the ground, form the Rejected workings; in reality merely an open work on the outcrop of a bed of conglomerate.

Operations, however, have been principally confined to the old Success ground, and the extent of the open-work is indicated on the mining plan which forms Plate II. So far as may be gathered at the present time the auriferous conglomerate, which did not differ from any of the other auriferous beds, varied in thickness from 18 inches to two feet. The table below gives the total gold yield, so far as can be gathered from the official figures; the 547 tons of ore crushed were in all probability obtained from this portion of the lease.

Table showing the Yield of the Success Extended Conglomerate.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
Previous to 1897	32·00	42·00	1·31
1897	*Nil*	*Nil*	...
1898	305·00	349·25	1·14
1899	110·00*	115·00	1·04
1900	*Nil*	*Nil*	...
1901	100·00	33·00	·33
Total	**547·00**	**539·25**	**·98**

* The 96 tons yielding 34·40ozs. from the Cook's Hill workings, credited in the official return to the Success Lease, are not included in this total, but are included in the yield of M.R.C. 6L.

SUCCESS, G.M.L. 119L.—This 24-acre lease, as it now stands, includes within its boundaries the old Barney's Hill United, G.M.L. 276 (upon which most of the work has been done), and a portion of the Success, G.M.L. 352.

The conglomerate worked on Barney's Hill lies at about the highest altitude of any of the beds at present opened up, being about 100 feet vertically above that in Grant's Hill. The workings lie pretty nearly upon the summit of the hill and along its southern slopes; the bed has been stripped along its outcrop for some distance round the southern and western slopes, and a vertical shaft 25 feet in depth has been sunk, intersecting a drive put in along the conglomerate for some distance from the outcrop.

Over three hundred tons of ore have been raised from the Barney's Hill workings. The figures given in the table as being

the yield of the present Success Lease were derived from ore obtained exclusively from the Barney's Hill workings.

Table showing the Yield of the Success Conglomerate.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
Previous to 1897	80·00	100·15	1·25
1897	246·00	228·00	·92
1898	12·00	23·10	1·92
Total	**338·00**	**351·25**	**1·03**

Barney's Hill No. 1 North, G.M.L. 24L (330).—This six-acre lease, which was abandoned in 1897, embraces the workings (Plate II.) lying near the western angle of G.M.L. 119L. Operations have been confined to a bed of very coarse ferruginous conglomerate, containing very large ellipsoidal boulders. At a slightly lower level on the north side of a gully flowing southwards from the south-west angle of G.M.L. 119L is a vertical shaft, 50 feet in depth, in which five or six feet of water were standing. This shaft, which was inaccessible, had been carried down through conglomerate of the usual type, and, judging by the material at grass, it contained a little pyrites. A characteristic portion of the pyritous conglomerate [**5803**] yielded no gold on assay in the official laboratory.

The only returns from the Barney's Hill United Lease appear to have been previous to 1897, when a small crushing of 20 tons yielded 25ozs. of gold, or at the rate of 1·25ozs. per ton. These figures indicate that portions of the conglomerate, in this part of the field, are auriferous.

Mineral Reward Claim, 6L.—This Reward Claim, which comprises an area of 320 acres, includes within its boundaries the old leases:—Golden Crown, G.M.L. 365 (31L); Beaton's Hill, G.M.L. 373 (37L); Cook's Hill, G.M.L. 412 (47L); Rejected No. 2, G.M.L. 416 (50L); together with parts of Golden Promise No. 1, G.M.L. 67L, and Central No. 1, G.M.L. 69L.

Near the easternmost angle of G.M.L. 119L, and to the north of Dean's Hill, are a series of extensive workings upon what was originally the Golden Crown G.M.L. 365, at an altitude of over 200 feet above the low ground at the base of the formation. All the ground on the flanks of the hill below these workings has been dryblown, and, during Mr. Inspector Becher's term of office, the average winnings from this source are stated to have amounted to about 18dwts. per man per day. The conglomerate, which lies in the locality practically horizontally, is of the usual ferruginous type, containing large pellets of hematite. A typical sample of this highly ferruginous variety from the open-work [**5806**] assayed in the

departmental laboratory gold at the rate of 4dwts. 2grs. per ton. The total returns from the Golden Crown workings, as shown in the table below, gives the yield as 189·90ozs. obtained from the milling of 223·60 tons of ore, or at the rate of ·84oz. per ton.

What is known as the Cook's Hill workings are situated due east of W.R. 2L. Cook's Hill is said to have derived its name from Mr. Nat. Cook, who is credited with being the first discoverer of gold at Nullagine in 1886. A good deal of work must have been done at one time or another, but as operations have been abandoned for some considerable time there is little to be seen.

By far the larger portion of the hill appears to have originally been covered with a gritty and ferruginous sand (the residual decomposition product of a sandstone) underlaid by a kaolinic deposit which carried waterworn boulders. It is noteworthy that while the material from the hill was being crushed several small diamonds were met with in the battery boxes; reference however will be made to this subject on a later page. The Cook's Hill deposit lies not very far from the base of the Nullagine Series. The total returns from the Cook's Hill workings, as shown in the table below, give the yield as being 140·10ozs. obtained from the milling of 348 tons of ore, or at the rate of ·40ozs. per ton. In this return an effort has been made to credit Cook's Hill with the yield actually obtained from the ore raised.* The return from the Diamond Reward Claim, M.R.C. 6L, as shown in the general table at the end, is really the result of the ore obtained from the Cook's Hill workings, and there seems to be good reason for believing the 1899 return from the Success Lease 27L includes 96 tons of ore from this same source. This latter yielded a return of 34·40ozs. of gold, or at the rate of ·36ozs. per ton. The workings on Beaton's Hill, which lie to the west of those last described, the hill upon which work has already been carried out, comprises about four acres, and is covered by a deposit of laterite stated to be about ten feet in thickness. Beneath the laterite occurs a more or less variable thickness of almost horizontal beds of sandstone and conglomerate. The bed which was worked lies near the base of the hill, and is said to rest directly upon a bedrock of slate, and the gold is said to have been traced thereto by the alluvial workers in the adjacent gully on the north.

Two shafts, now inaccessible, have been sunk to depths stated to be 35 and 40 feet respectively, and levels driven therefrom.

Mr. Beaton, one of the original holders of the ground, and after whom the hill is named, is stated to have worked a considerable distance in under the hill, and to have taken out a large quantity of gold by crushing the material roughly by hand, screening it, and sluicing it at the river. There appears, however, to be no official

* The late Mr. Becher's note-books, 1896, state that "since first worked Cook's Hill has yielded about 4,000ozs. of gold." There is no reason for doubting the accuracy of this statement, but it is quite clear that this amount has not been officially recorded in the statistics, and may possibly never have been reported to the Government.

record of the yield from the old Beaton's Hill Lease, and in all probability any returns therefrom have been included in that from sundry claims.*

Table showing the Yield of the Conglomerates of the Mineral Reward Claim 6L.

Year.	Name of Lease.	Ore crushed.	Gold therefrom.	Rate per ton.	Total Ore crushed.	Total Gold therefrom.	Average rate per ton.
		tons.	ozs.	ozs.	tons.	ozs.	ozs.
Previous to 1897	Golden Crown, G.M.L. 31L	32·60	50·90	1·56			
1898 ...	Do. do. ...	191·00	139·00	·72	223·60	189·90	·84
1898 ...	Cook's Hill, G.M.L. 47L ...	22·00	26·30	1·19			
1899 ...	Do. do. ...	96·00	34·40	·36			
1900 ...	Do. do. ...	230·00	79·40	·34	348·00	140·10	·40
	Total				571·60	330·00	·49

Golden Promise, G.M.L. 380 (39L, and subsequently Golden Promise No. 1, 67L.)—The abandoned workings upon what was originally embraced by this lease are coterminous with the north-western boundary of the Mineral Reward Claim, 6L (Plate I.), and at an altitude of about 180 feet above the general level of the plains. A vertical shaft, 20 feet in depth, had been put down through conglomerate and intersected the open-works at a lower level. The auriferous portion of the conglomerate was a ferruginous band varying from 15 inches to 2 feet in thickness.

The following table gives the yield of the crushings :—

Table showing the Yield of the Golden Promise Conglomerate.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1897	84·00	68·65	·81
1898	88·00	81·20	·92
Total	172·00	149·85	·87

Sundry Claims from the District generally.—In addition to the returns given above in connection with sundry claims, which it is impossible to specify individually, there have been recorded over 6,000ozs. of gold. These figures are given in such

* The late Mr. Becher's note book, 1896, states :—"Return, September, 1896, 1 ton, yielding 2ozs. 2dwts. 12grs. Since Beaton's Hill was first worked it has yielded about 3,000ozs. of gold." This amount does not appear to have been officially recorded in the statistics, and may possibly never have been reported to the Government.

detail as is possible in the table below. There are, however, no means of ascertaining what proportion of these figures are to be credited to that portion of Nullagine embraced by the geological map (Plate I.); it is, however, possible that they include returns from the Elsie, Mosquito Creek, Nullagine, and 20-mile Sandy, which centres are included in the "Nullagine District," as defined by the Mines Department.

Table showing the Yield from Sundry Claims, Nullagine.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1897	100·00	143·65	1·43
1898	92·00	213·90	2·32
1899	1,066·70	{ 2,695·95 *38·45	2·52
1900	1,008·60	{ 2,433·30 *11·00	2·41
1901	248·25	336·54	1·35
1902	293·05	343·67	1·17
1903	145·90	609·30	·41
1904	830·65	{ 1,308·65† *23·75†	1·57†
Total	3,785·15	8,158·16	2·15

* Specimens. † Fine ozs.

Diamonds.

The occurrence of small diamonds at Nullagine having been brought under the notice of the Government, a report was obtained on the subject by the then Premier from Mr. Fred. F. Groom in the year 1896.* From Mr. Groom's report it appears that the greater number of the most valuable diamonds were washed out of the conglomerate forming Brook's Hill, which was being treated for gold, and others were found in the stamper boxes after crushing a few tons of the conglomerate. Mr. Groom states: "There is no doubt, in my opinion, that the diamonds are enclosed in the conglomerate, . . . and such as have been found by diggers in washing for gold have been released by the gradual decay of the rock . . . On the last day of my stay in Nullagine, I was present at the cleaning up of the battery after crushing about two tons of stone taken from the hill . . . On carefully panning off the gravel left in the stamper boxes nine small stones were found, varying from the size of a pin's head to a pepper-corn, or from $\frac{1}{16}$ to $\frac{1}{2}$ carat in weight. I put the lot into the scales, they weighed $1\frac{1}{2}$ carats, and it took the four largest to weigh one carat. I was informed that

* Report of a visit to Nullagine, Pilbara District, to examine the country reported to be diamond-yielding. Appendix 4. Report of the Department of Mines for the Year 1895. Perth: By Authority, 1896, p. 27.

Mr. Brooks found one diamond for which he obtained £76, another he sold for £28. These, with one other, valued by the finder at £12, were all the diamonds I could hear of as having been of any value; the last-mentioned stone was described as being bright yellow."

During the course of my examination of the district no diamonds came under my notice, there are, however, in the collection of the Western Australian Museum (*a.*) four small diamonds presented by Messrs. Brook Bros. in 1896, and (*b.*) four small diamonds taken from the battery boxes when cleaning up a crushing of conglomerate, one from Cook's Hill, presented by Mr. Inspector S. J. Becher in 1896. The returns of a crushing of 230 tons of conglomerate from the Mineral Reward Claim 6L in 1900 show, in addition to 79·40ozs. of gold, twenty-five small diamonds, the value of which, however, is not stated. From the particulars given above it seems perfectly clear that the presence of diamonds in the conglomerates near the base of the Nullagine Series is authentic. The occurrence of such renders it possible that they are not isolated instances, though the interest is at the present time more scientific than commercial.

Name of	1901.		1902.		1903.		1904.		Total.	
	Ore ushed.	Gold therefrom.	Ore crushed.	Gold therefrom.	Ore crushed.	Gold therefrom.	Ore crushed.	Gold therefrom.	Ore crushed.	Gold therefrom.
	ons.	ozs.	tons.	ozs.	tons.	ozs.	tons.	ozs.	tons.	ozs.
	..	..	..	..	..	..	..	..	266.00	702.70
Day Dawn	..	..	..	..	..	..	..	..	..	..
Do. N	..	..	..	..	..	..	..	..	..	..
Do. N	..	..	..	..	..	..	..	..	30.00	90.00
Promise	..	..	..	..	..	..	..	..	20.00	56.60
Fisher's Rew	..	..	..	..	..	..	..	..	..	..
Try Again	..	..	..	..	..	..	..	..	121.00	421.10
Victory	..	..	..	..	..	..	..	..	22.00	63.00
Do.	2.75	6.10	..	..	..	..	..	..	105.95	492.95
Golden Eagle	..	..	..	..	..	..	..	..	..	..
Do.										
	..	..	..	..	..	..	..	..	170.50	634.45
Victory Eas										
	25.50	181.00	..	..	..	..	..	..	114.50	595.35
Walter's Folly										
	..	..	..	..	..	..	..	..	..	..
Victory	..	..	..	..	..	..	..	..	..	..
Marquis	..	..	..	..	..	..	..	..	28.00	14.00
Sunrise No.	..	..	..	..	..	..	..	..	..	..
Sunrise	..	..	..	..	..	..	..	..	..	..
Gt. Eastern	..	..	..	..	..	..	..	..	190.00	224.40
Gt. Eastern	..	..	..	..	..	..	..	..	170.00	202.75
Great Eastern	..	..	..	..	..	..	..	..	..	..
Do. N										
	..	..	..	..	..	..	..	..	..	..
Scottish Chie	..	..	..	..	..	..	..	..	..	..
Enterprise										
	28.25	187.10	..	..	..	..	..	..	1,237.95	3,497.30

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1901.		1902.		1903.		1904.		Total.	
re hed.	Gold therefrom.	Ore crushed.	Gold therefrom.	Ore crushed.	Gold therefrom.	Ore crushed.	Gold therefrom.	Ore crushed.	Gold therefrom.
ns.	ozs.	tons.	ozs.	tons.	ozs.	tons.	ozs.	tons.	ozs.
..	..	..	..	..	..	..	..	..	..
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..	..	..	..	..	..	..	..	998.00	943.10
8.00	614.53	300.00	128.51	777.00	94.10	..	..	2,435.00	837.14
..	..	..	..	..	..	..	..	..	..
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0.00	33.00	..	..	..	..	..	..	643.00	574.65
..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	338.00	351.25
..	..	..	..	..	..	..	..	20.00	25.00
..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	223.60	189.90
..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	172.00	149.85
..	..	..	..	..	..	..	..	22.00	26.30
..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	85.40	40.70
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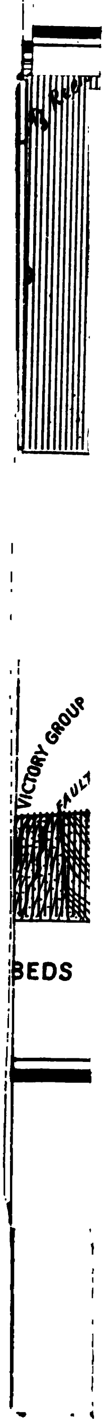
..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	230.00	79.40
58.00	647.53	300.00	128.51	777.00	94.10	..	..	5,167.00	3,217.29


VICTORY GROUP
BEDS

B.—WARRAWOONA.

(With a Geological Sketch Map and three Mine Plans.)

General Geology.

The mining centre of Warrawoona lies about 15 miles from Marble Bar, and embraces the south-eastern extension of that belt of auriferous rocks which form the Marble Bar, Yandicoogina, and Mount Elsie Zone, to which reference has been made in a previous report.*

The district of which Warrawoona is the centre is formed of a lofty serrated razor-backed ridge (with several minor parallel ones) trending generally north-west and south-east. It is upon the southern slopes of the main ridge, and what perhaps may be conveniently called the foothills, that all the auriferous quartz reefs occur. The general trend of these ridges has been determined by the outcrop of the siliceous rocks of which they are everywhere made up.

Several important watercourses occupy the longitudinal valleys (carved out of the softer strata) between the different ridges, whilst those creeks which breach them almost at right angles to the general strike of the schists afford many excellent sections. They thus shed light upon many obscure points in connection with the geological features of the district. The plateau which extends for miles on either side of what may be called the main axis owes its relatively smooth and rounded contour to the general homogeneity and practically equal weathering of the rocks by which it is underlaid, *e.g.*, granite, etc.

The geological formations of the area embraced by the Geological Sketch Map of Warrawoona (Plate III.) are represented by a series of sedimentary rocks, quartzites, and conglomerates, many of which have been converted into quartz schist, mica schist, etc., by dynamic agencies. Associated with these undoubted sedimentary strata are a series of igneous rocks which have likewise been rendered partly schistose by the same causes. The exact relation these igneous rocks bear to the sedimentary series has not been worked out, a problem which would perhaps be difficult in this particular portion of the district. The southern portion of the district is occupied by granite, which appears to have been brought into position by a fault, trending generally north-west and south-east.

Somewhat akin to the southern granitic mass are those dykes and masses of felspar-porphyry which occupy the northern limits of the map; in all probability these latter have some intimate connection with the large area of granite which occupies the country to the north of that embraced by the Warrawoona Map. There seems however to be strong reasons for believing the granite to be intrusive into what may conveniently be termed the schists, and that portions of it have been affected by earth movements of varying degrees of intensity after the intrusion took place.

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* Bulletin No. 15, p. 33 *et seq.*

In addition to these rocks, the field is traversed by a remarkably persistent series of north-west and south-east greenstone dykes. These dykes, which have been mapped with some degree of accuracy, traverse the centre of the auriferous portions of Warrawoona, approximately at right angles to the general trend of what may be called the auriferous zone. Besides these relatively newer greenstone dykes, there are others which are intimately associated with the older rocks of the district. These older dyke rocks are often rudely cleaved and foliated, and seem to occur in intimate connection with, or parallel to, the principal structural lines of the district, viz., north-west and south-east. These older cleaved or foliated dykes can be seen in many places to be pierced almost at right angles to their general trend by the newer or uncleaved series.

Within the area embraced by the map, there is a large development of those laminated or banded quartz veins which form such conspicuous features in this district. These, owing to their economic importance, have been laid down upon the map with a considerable degree of accuracy. One conspicuous band traverses the whole length of the district, viz., six miles, and forms the centre of the main auriferous zone, which latter is of considerable longitudinal extent, though averaging only about 20 or 30 chains in width.

Of the different rocks occurring in the Warrawoona area, not much can be said, in the present state of our knowledge, of their relative ages, nor their true position in the geological time scale.

The following is a list of the various rock groups arranged in tabular form:—

Warrawoona Beds. Age undetermined (? Archæan)	(*a.*) Altered Sedimentary Series (quartzites, conglomerates, quartz, and mica-schist, etc.)
	(*b.*) Metamorphic Igneous Rocks (greenstone, magnetite, and serpentinous schist, and more or less allied sheared basic igneous rocks)
Granite and Felspar Porphyry.	
Basic Dykes	(*a.*) Newer
	(*b.*) Older

Warrawoona Beds.

The strata of the Warrawoona Series form part of that auriferous zone which includes Marble Bar, Yandicoogina, and Mount Elsie, and to which reference has already been made in a former report.* In the Warrawoona neighbourhood, however, much better opportunities for investigating the strata present themselves than in any other portions of the district yet examined.

An examination of the district, which is of great importance by reason of its gold yield, shows that the Warrawoona Beds can be separated into two distinct portions sharply differentiated from each other, viz., an acidic and a basic series. The acid series is made up of highly siliceous beds, dipping at varying angles to the

* Bulletin No. 15, p. 33 *et seq.*

north-east and trending generally north-west and south-east. The beds, which there are very good reasons for believing to be of sedimentary origin, consist of fine-grained flaggy quartzites, sheared conglomerates which still retain traces of their original character, mica and quartz schists, together with certain other fine-grained siliceous rocks which seem to have lost all trace of their original character. There are, in intimate association with these, certain other acidic rocks, which may eventually prove, on closer examination, to be highly-sheared felsites; it has however not been found possible, owing to the small scale of the map, to delineate the area over which these doubtfully acidic igneous rocks extend; it is, however, but small.

In hand specimens, this doubtful rock [**5788**] is in reality a quartz-sericite schist, with eyes or lenticules of a fairly soft mineral around which the finer foliation of the matrix sweeps in very graceful curves. The mineral forming these eyes has been examined both chemically and microscopically by Mr. E. S. Simpson, who reports that "they appear at one time to have been single crystals of probably potash-felspar, but are now completely altered into a mixture of at least three minerals, viz., free quartz; a non-hydrous crystalline silicate of alumina, probably andalusite; and a hydrous silicate of alumina and alkalies, probably a mica. The specific gravity of these 'eyes' is variable but averages 2·85. Their average composition is:—

Silica, SiO_2	76·0
Alumina, Al_2O_3	21·4
Ferrous Oxide, FeO	·3
Lime, CaO	*Nil*
Magnesia, MgO	Trace
Potash, K_2O	·4
Soda, Na_2O	·3
Combined Water, H_2O	1·6
	100·0"

Examined under the microscope these porphyritic crystals are found to be shattered and broken, and their edges present that peculiar peripheral granulation so characteristic of crystals and fragments which have been subject to intense crushing. A micro-photograph of one of these shattered and broken crystals forms Fig. a, Photograph "H" (facing page 72.) The matrix in which the larger crystals are embedded presents a fine mosaic of quartz, felspar, and a little sericitic mica through which are streams of numerous yellowish brown crystals. These crystals which occur in the form of short, and sometimes geniculated, pear or kite-shaped prisms, with straight extinction under crossed nicols, are in all probability rutile. It is difficult, with the evidence at present available, to be sure of the exact nature of the original rock, but it may possibly have been produced by the crushing of a felspar porphyry. Unaltered felspar porphyries do occur in the country just to the north of this, hence it is possible that this rock may be merely a transmitted variety of them.

The specimen, a quartz sericite schist [**5760**], is another variety of a rock identical in many respects with that last described, except that there are no large porphyritic crystals. Streams of rutile are common, in addition to numerous colourless acicular crystals of what seem to be apatite.

A quartz schist [**5761**] from near the Ironclad Battery, M.A. 1, consists microscopically of a mass of irregular interlocking grains of quartz, with irregular patches arranged in the form of bands, of what under crossed nicols is neither more nor less than a fine quartz mosaic. The quartz exhibits undulose extinction. A little sericitic mica occurs in places.

Another quartz schist [**5762**] from a different portion of the mass, when examined under the microscope consists of a very fine-grained mass of quartz, showing undulose extinction, together with a little sericitic mica, the foliæ of which are often very much distorted.

A fairly fine-grained quartzite [**5764**] which under the microscope is found to contain numerous fairly large angular and sub-angular quartz grains set in a much finer-grained quartz mosaic. This rock contains numerous brown patches and strings of mica (?) together with a little pyrites.

Associated with these quartzites and quartz schists is a very calcareous rock [**5765**] which outcrops near the Ironclad Battery. In hand specimens the rock is of a pale salmon colour, is distinctly banded, weathers very much like a limestone, and effervesces briskly upon the application of dilute acid. An analysis of this rock is given in the table on page 66. Very little can be made out by microscopic examination, even with a $\frac{1}{4}$-inch objective, and it is not quite clear whether the rock is a limestone or merely an extreme phase of the alteration of one of the igneous rocks of the district. The field relations however seem to point to its being distinctly interbedded with the quartzites and quartz sericite schists.

A short distance north of the Seven Dials, just outside the limits of the geological map, is a conspicuous hill forming the western extremity of a bed of metamorphic grit (or quartzite) and conglomerate, dipping at angles averaging about 50 degrees to the north-east; the quartzite rests upon greenstone schist, and has been affected by the same foliation which affects the latter. The quartzite is traversed by bands of laminated quartz of the type prevailing in the district. Most of the pebbles in the conglomerate are flattened out almost beyond recognition, though in some places they are well shown on the weathered surface of the rock.

Among the quartz schists which form the summit of what may be called the main range of Warrawoona is a bed which here and there contains what at first glance appears to be fossil wood [**5766**]. A characteristic specimen of this silicified wood (?) has a length of about $4\frac{1}{4}$ inches; cross sections of it are ellipsoidal in shape, the major axis being about three-quarters, and the minor axis about five-eighths of an inch in length. Microscopical sections both transverse and longitudinal were prepared, and were submitted

along with the specimen to Mr. Etheridge of the Australian Museum, Sydney, who was unable to detect any trace of organic structure in them. It is, however, quite possible that the dynamic metamorphism which these rocks have undergone may have entirely obliterated all traces of organic structure, and that some form of plant life existed at the time these beds were deposited.

Adjoining Lease 479, the Juneau, is a schist forming part of the main series which presents many points of interest.

In hand specimens the rock [**5787**] is of a very light brownish colour, and is distinctly foliated. In addition to quartz, which forms no inconsiderable portion of the rock, there are numerous elongated crystals of a clear glassy mineral, the cleavage faces of which are very distinctly marked, and which give a distinctive character to the rock. Under the microscope the rock is found to be made up of clear and unaltered fragments of felspar, very few of which however are twinned, quartz polarising in brilliant colours, a little colourless mica and a reddish brown substance, which may result from the alteration of some mineral rich in iron. The rock is clearly a felspathic schist, the field relations of which point to its being of clastic origin.

The greenstone schists and other allied rocks of Warrawoona occupy a large area of country, and vary very much in the width of their outcrop. It is of course possible that this may in part be due to differences in the folding (?). A feature in the physical structure of the greenstone schists which may have some significance is what may be called an anticline of foliation, the centre of which trends generally in the same direction as the main structural lines of the district. This is well exposed at a point a little distance to the south of the Gauntlet No. 3 North-West Lease.

A very important feature of these greenstone schists is the presence among them of unfoliated basic rocks, which sometimes occur in the form of lenticular belts of (in certain places) considerable horizontal extent. Several excellent sections in the district show these basic rocks passing by scarcely perceptible gradations into the greenstone schists.

It is possible that as the strike of these belts of massive basic rocks more or less coincide with that of the general foliation of the district, they may occasionally be mistaken for some of the older basic dykes, which have a parallel strike.

In one or two localities are belts of magnetic-schist, in the centre of some of which are uncrushed "eyes" (of large dimensions) of greenstone occurring in such a way as to indicate that the margins only of the mass have been crushed down into schist. Many of these schists contain very large quantities of magnetite, such as give a very distinctive character to the rock.

The foliated or sheared greenstones on the Gauntlet Lease contain large brown crystals [**5767**], a combination of cube and octahedron of iron ore, viz., limonite pseudomorphs after pyrites.

Many of these crystals are about an inch in length. In other portions of the field, the surface of the unfoliated greenstone is strewn with similar limonite crystals. Some of the greenstones are very much decomposed, and some of the constituent minerals are largely replaced by carbonates, giving the rock a very characteristic weathered surface at first sight, very suggestive of the weathered surface of some limestone.

The chemical composition of several of these greenstones and their allies is given in the table of analyses, page 66.

In mineralogical constitution the rocks present very many points of similarity.

The country rock [**5755**] of the Golden Gate Reef is a soft green talcose-chloritic schist, the chemical composition of which is shown in the table on page 66. The crystals of talc which are often of considerable length, have been as may be seen under the microscope, broken and torn apart by the stresses and strains to which the rock has been subject. The exact relation of this schist to the surrounding greenstone cannot be precisely determined, as access to the underground workings of the mine was not obtainable.

The rock [**5777**] which forms the matrix of the Imperialist Reef is a fine-grained talc-chlorite schist, identical with that of the Golden Gate. The analyses of the two rocks present also many points of similarity.

The Tom Thumb Reef is enclosed in a fine-grained chlorite schist [**5756**] which, when examined under the microscope, is found to be made up of quartz, felspar, chlorite, and epidote (?). The chemical composition of this rock is given in the table on page 66.

The country rock [**5768**] forming the matrix of the May-be reef is of a somewhat similar character, and, as its field relations indicate, owes its origin to the compression of a massive greenstone. Its mineralogical constitution does not appear to differ in any very essential feature from the other schistose greenstones; its chemical composition is given in the table quoted above.

The Gauntlet Lease is traversed by a band of chlorite schist [**5779**] in many respects identical with that forming the Tom Thumb Reef. The chemical composition of this rock agrees very closely with some of the massive diabases of other portions of the field.

At a point about 10 or 12 chains to the north-east of G.M. Leases 531 and 593 is a lenticular mass of a serpentinous rock [**5757**], the chemical composition of which is set forth in the table of analyses on page 66. The mass has a length of about 20 and a maximum width of about five chains, whilst its longer axis is in a direction of north-west and south-east, parallel to the main structural features of the district.

A very large quartz reef outcrops in the centre of the mass, but does not extend into the surrounding rocks. The serpentine is enclosed in the mass of acidic rocks, but in such a condition that its original condition is not quite clear; there seem, however,

grounds for believing it to have been brought into its present position by a fault.

The massive greenstones vary very much in grain; they all contain more or less hornblende (sometimes fibrous) and its alteration product chlorite, quartz, felspar, and calcite, together with an iron ore. Some, however, are very calcareous, and effervesce briskly on the application of acid.

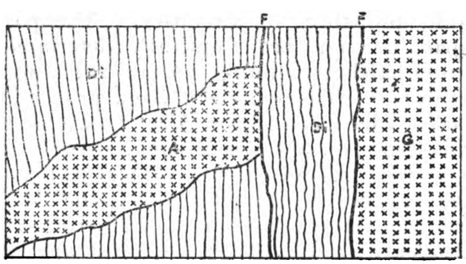
Detailed petrographical examination of all these rocks has not yet been made, but it is hoped to approach this subject at a later date, as opportunity offers.

Granite and allied Granitic Rocks.

The granite, which is of the normal type, occupies a rudely triangular patch on the southern boundary of the map, about 200 chains in length and about 40 chains in maximum width. It, however, extends for many miles far beyond the limits of the map. There seems good reason for believing that the granite is intrusive into the greenstone schists, though its northern boundary, to the south of the Imperialist Reef, is marked by a fault.

The exposure on the hillside, a plan of which forms Fig. 5, reveals the relationship of the granite and greenstone schists to each other.

FIG. 5.



PLAN SHEWING THE FAULTED NATURE OF THE GRANITE JUNCTION Sth OF THE IMPERIALIST GOLD MINE WARRAWOONA PILBARA G.F.
G. GRANITE A. APLITE Di GREENSTONE SCHIST F FAULTS

In this section the greenstone schists abut sharply against a smooth wall of granite, which is inclined at an angle of from 45 to 55 degrees to the north, this angle being practically coincident with the dip of the foliation planes of the schists. A few inches of schist separate an aplite dyke of four feet in thickness from the main granite mass. The dyke traverses the schists in a direction almost at right angles to their general strike. A quartz reef occurs along the faulted junction some distance east of this point, in close proximity to the newer greenstone dykes, which traverse the centre of the field. There is no very clear evidence of a marked banding or foliation in the granite anywhere in the southern portion of the district. In that large granite mass on the north, just outside the limits of the map, it possesses a rude foliation or

banding, which is parallel to the general strike of the foliation of the schists forming the higher ground to the south.

Whether this banding has any connection with the general foliation of the district, or is an original feature of the granitic magma, has not been satisfactorily determined. If this banding in the granite is not an original feature, then it would seem to indicate that both it and the Warrawoona beds were subject to the same set of stresses and strains which were set up in the interval separating the beds of the Nullagine from the older series.

The north-east angle of the map is made up of felspar-porphyry [**5792**] sometimes occurring in the form of dykes. The rock, when a freshly broken and unweathered surface is examined, is found to be of a grey colour, with numerous crystals and fragments of a cloudy white felspar (some of which show twinning) set in a fine-grained matrix.

Examined under the microscope, the rock is found to be made up of a micro-crystalline ground mass of quartz, together with a small proportion of orthoclase, in which are embedded large crystals and fragments of felspar but no quartz. A relatively large quantity of biotite of a brownish colour occurs in many cases, arranged in bands which sweep round the porphyritic felspar in a manner paralleled by the flow structure developed in some volcanic rocks. The brown colour of the mica often passes gradually into a bright green, the result, probably, of alteration. The porphyritically developed felspar has not been optically determined, but the characteristic cross-hatched twinning in some parts would point to its being an orthoclase. The relatively large proportions of lime and soda as disclosed by the analysis [**5792**] shown in the table on page 66, would seem, on the other hand, to indicate that the felspar belongs to the lime-soda series. This felspar-porphyry is practically identical in its character with the Duffer's Creek porphyry referred to in the analysis [**5392**] of the rocks from Pilbara, on page 12 of Bulletin No. 15. There are few if any large porphyritically developed felspars in this latter rock, which perhaps may be held accountable for the smaller percentage of potash and lime, as shown in the analysis; in all other respects the two rocks are identical.

There does not seem, so far, to be any intimate relationship subsisting between this porphyry and the main granite mass, as developed on either side of the main axis of Warrawoona. The fact that it shows no signs of even a quasi-foliation, which characterises some portions of the granite, would seem to indicate that the porphyry is of later date than the granite. It may, perhaps, have some connection with the volcanic activity which prevailed during the period of the deposition of the Nullagine Series.

The geological age of the granite cannot, as yet, be exactly determined; it is, certainly, newer than the Warrawoona Beds, into which it is intrusive. The granite passes beneath the Nullagine

Series, which the evidence* so far available seems to point to being of Cambrian Age; in this case the granite would be Pre-Cambrian.

Basic Dykes.

The basic dykes of Warrawoona belong to two different periods; the district, however, furnishes no satisfactory evidence as to the exact age of each set.

The newer basic dykes traverse the whole width of the field in a general north-east and south-west direction, and extend for very many miles to the north and south of the country examined. The system of newer dykes intersects the auriferous belt between the Bow Bells and the Gauntlet groups of reefs almost at right angles to the general trend of the series. In no case do these dykes attain any great thickness, and their breadth varies greatly in different parts; the thickness, as shown on the Geological Map of Warrawoona (Plate III.), has been somewhat exaggerated, in consequence of the small scale employed. Such few cross sections as may be seen of them indicate that they approach very closely to the vertical.

The rocks of which they are composed are basic compounds, an analysis of the most typical [5773] is shown in the table on page 66.

In hand specimens these dyke rocks vary from coarse to medium grain, and are seen to consist of a greenish grey felspar, together with a ferro-magnesian constituent and an iron ore. Under the microscope the rock is found to consist of allotriomorphic crystals of a plagioclastic felspar, many of which present that turbid mealy aspect so characteristic of alteration, together with brown or almost colourless augite, and a little enstatite (?) passing into bastite (?). The place of some of the augite is taken by a pale green fibrous decomposition product which may be chlorite. The iron ore, which is often represented by skeleton crystals, is probably ilmenite. The rock is therefore a diabase.

The regular continuity of the system of dykes has been interrupted in the vicinity of their intersection with the auriferous series. From the position in which this interruption occurs, it would seem that these newer dyke rocks had undergone considerable movement since their injection. The somewhat curved and distorted fragments or isolated patches all point to a series of later movements along lines parallel to that of the main trend of the auriferous belt of Warrawoona.

The older series of dykes have a general trend approximately at right angles to that of those previously described, and are in some cases intersected by them. Like the newer dykes they are all basic compounds. In some cases they have been crushed and sheared into a schistose greenstone, which occasionally takes the form of a schist which has a characteristic weathered outcrop, very suggestive of a calcareous schist. These sheared dykes are all indicated upon the map.

* Supra, p. 27.

Table of Analyses of Rocks from Warrawoona.

By E. S. Simpson.

Geological Museum No.	5755	5756	5757	5765	5768	5773	5777	5778	5779	5780	5781	5792	5793
Specific Gravity	2·94	2·88	2·91	2·76	2·79	3·00	2·93	2·82	2·62	2·84	2·58	2·73	3·07
Silica, SiO_2	43·25	43·47	30·63	17·63	41·88	50·48	43·90	45·68	55·00	48·54	65·75	69·14	50·20
Alumina, Al_2O_3	9·98	14·87	1·68	4·28	10·13	23·18	9·13	8·94	24·30	13·67	19·39	14·71	17·95
Ferric Oxide, Fe_2O_3	1·93	3·35	5·94	1·97	*Nil*	3·07	1·20	2·23	3·93	2·13	·51	3·47	9·49
Ferrous Oxide, FeO	10·04	14·93	4·72	*Nil*	9·59	8·86	10·48	5·91	7·53	10·04	3·05	·78	4·20
Magnesia, MgO	22·48	12·64	32·30	14·74	7·20	·64	19·17	12·25	2·30	4·54	2·36	1·09	2·26
Lime, CaO	5·31	1·18	Trace	24·63	13·06	7·47	7·46	12·56	·18	6·46	*Nil*	4·83	7·76
Soda, Na_2O	·49	·55	·41	·92	1·30	2·17	·57	1·82	2·43	3·58	·93	4·24	1·01
Potash, K_2O	Trace	·13	·11	·43	·10	·83	·09	·12	Trace	·04	4·66	1·00	·14
Combined Water, H_2O	4·74	6·82	·52	·70	3·51	1·71	4·68	1·92	3·14	2·74	1·78	·08	3·04
Hygroscopic Water, H_2O ...	·20	·26	·15	·05	·07	·10	·04	·07	·27	·04	·10	·04	·10
Carbonic Anhydride, CO_2 ...	·17	*Nil*	23·03	34·94	11·60	·55	2·46	8·34	·98	7·14	·16	·40	1·12
Titanic Oxide, TiO_2	·50	1·48	·52	·20	1·15	·38	·30	·40	Trace	1·12	·66	·30	1·42
Pyrites, FeS_2 Fe	·03	·05	·09	*Nil*	·16	·14	·02	·04	Trace	·12	·11	Trace	·14
Pyrites, FeS_2 S	·04	·06	·11	*Nil*	·18	·16	·03	·05	...	·14	·12	...	·16
Manganese Protoxide, MnO ...	·54	·10	·11	Trace	·32	Trace	·05	·09	Trace	Trace	*Nil*	·21	·37
Total	99·70	99·89	100·32	100·49	100·25	99·74	99·58	100·42	100·06	100·30	99·58	100·29	99·36

5755.—Talc-chlorite schist. Golden Gate Lease, Warrawoona, Pilbara Goldfield. Analyst, E. S. Simpson.

5756.—Chlorite schist. Tom Thumb Lease, Warrawoona, Pilbara Goldfield. Analyst, E. S. Simpson.

5757.—Serpentine schist. Near Moolyella Gap, Warrawoona, Pilbara Goldfield. Analyst, E. S. Simpson.

5765.—Carbonated schist. Near Ironclad Battery, Warrawoona, Pilbara Goldfield. Analyst, E. S. Simpson.

5768.—Chlorite schist. May-be Lease, Warrawoona, Pilbara Goldfield. Analyst, E. S. Simpson.

5773.—Newer Diabase Dyke. Warrawoona, Pilbara Goldfield. Analyst, E. S. Simpson.

5777.—Talc-chlorite schist. Imperialist Lease, Pilbara Goldfield. Analyst, E. S. Simpson.

5778.—Older Greenstone Dyke. Warrawoona, Pilbara Goldfield. Analyst, E. S. Simpson.

5779.—Foliated Greenstone. Gauntlet Lease, Warrawoona, Pilbara Goldfield. Analyst, E. S, Simpson.

5780.—Greenstone. Bow Bells Lease, Warrawoona, Pilbara Goldfield. Analyst, E. S. Simpson.

5781.—Schist. Bow Bells Lease, Warrawoona, Pilbara Goldfield. Analyst, E. S. Simpson.

5792.—Felspar-Porphyry. North side of Main Range, Warrawoona, Pilbara Goldfield: Analyst, E. S. Simpson.

5793.—Greenstone. Warrawoona, Pilbara Goldfield. Analyst, E. S. Simpson.

Fissures, Faults, etc.

A very marked feature in the structure of Warrawoona is the occurrence of those bands of laminated quartz which traverse the whole length of the field, these being locally spoken of as "dykes."

These bands often rise in the form of rough serrated ridges, which, by virtue of their power of resisting denuding agencies, stand out in bold relief, and can be followed across country for, in some cases, miles. They are, wherever seen in section, either vertical or inclined at high angles to the north east. In the case of the crosscut from the south drive in the tunnel workings of the Bow Bells Mine (Plate IV.), a dip of 65 degrees was observed. Although this vein, as seen underground, proved to be ten feet in thickness, there did not appear to be any distinct line of demarkation between it and the country rock, the whole section in the crosscut suggesting a gradual replacement of the original rock along lines of maximum compression or foliation.

Similar cases of a gradual transition between the quartz and the country rock can be noticed in several cases along the summits of the ridges in the district.

Of these bands there are twelve in all, the most conspicuous and the most important being that which traverses the whole line of

leases across the field in a north-westerly direction. This particular vein is locally spoken of as "The Dyke," and it may be that it represents an old line of weakness along which disturbance has taken place at several distinct periods.

The other veins, it will be noticed, all taper off gradually along a line which is, approximately, parallel to the dyke, and are disposed somewhat in the shape of a fan, the ribs of which open out gradually to the west.

The mode of occurrence and ending off of these quartz veins is very suggestive of this line being a fault; to which the interruption in the continuity of the newer diabase dykes in the vicinity would seem to lend additional colour. There is, however, no sign of any such fault on the surface, and, in fact, owing to the nature of the surrounding rocks, any such might readily escape detection.

These laminated quartz veins have been subject to a certain amount of faulting, and all those which have any effective throw have been laid down upon the map. As all the veins have a very high underlie, a considerable vertical displacement might easily take place without having any very marked effect upon the outcrop.

When examined under the microscope, typical specimens of these laminated quartz veins [**5758, 5759**] present no features of any particular moment.

In addition to the laminated quartz veins previously mentioned, there is another type of fracture developed on the field, which makes itself manifest in two well defined bands, trending approximately parallel to them. These bands, which form a very pronounced feature in the landscape, are represented by a "sheeting" or "zoning" of the country rock, the width of which varies within very wide limits. The photographs "F" and "G," taken by the late Mr. S. J. Becher, give a graphic idea of the nature of these zones, which in reality result from the powerful compression to which the rocks have been subjected. There are, occurring in these bands, more or less extensive lenticules or "eyes" of quartz, parallel to the foliation; and many of these quartzes have a characteristic and distinct greenish hue [**5759**]. Fig. 6 shows a section across one of these compression fractures, with the characteristic quartz lenses, traversed by a reef of much newer formation. This newer reef is from 12 to 14 inches in thickness. The country rock traversed by this fracture has been silicified along the lines of compression, whilst the vertical slickensided faces indicate subsequent movement, which, however, may not have been very great. One of these bands of compression or shearing traverses the whole length of the Klondyke Boulder Lease (Plate VI.), parallel to the reef of the "Leader" type; it forms a very marked feature on the surface and stands out in bold relief. The foliæ, however, are not, in this section, vertical, but inclined at a very high angle to the north-east.

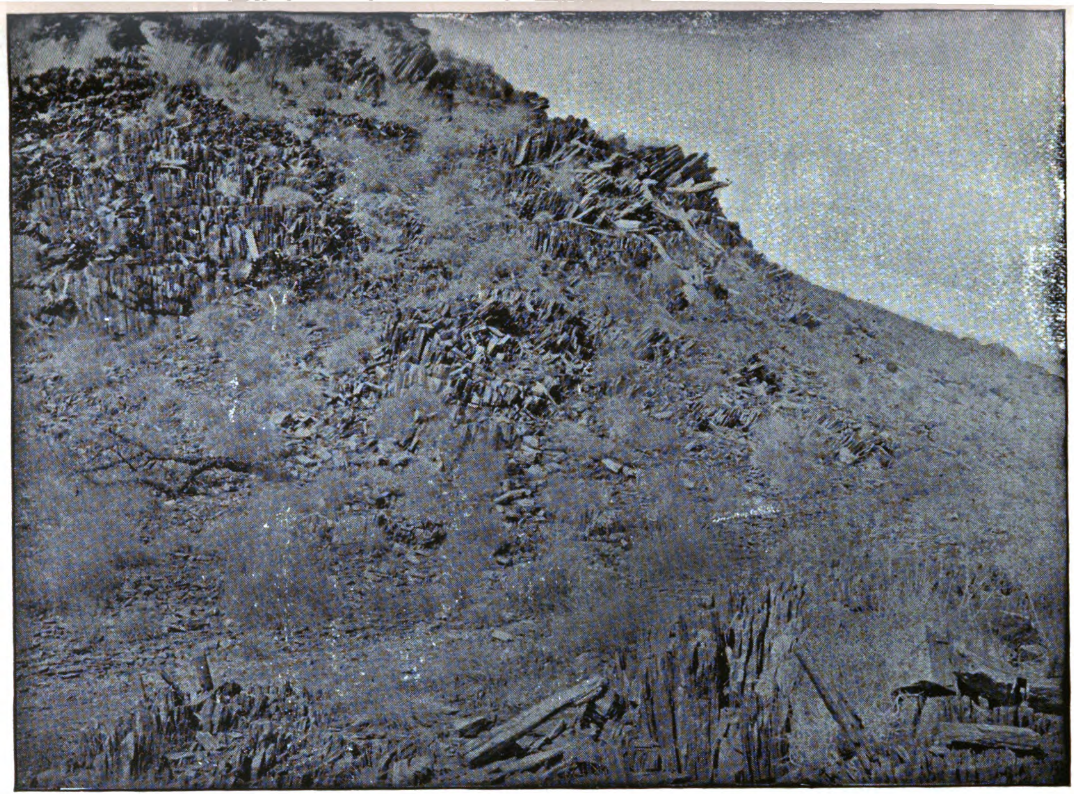


PHOTO.: S. J. BECHER.

Sheeted Zone in country rock, Warrawoona, Pilbara Goldfield.

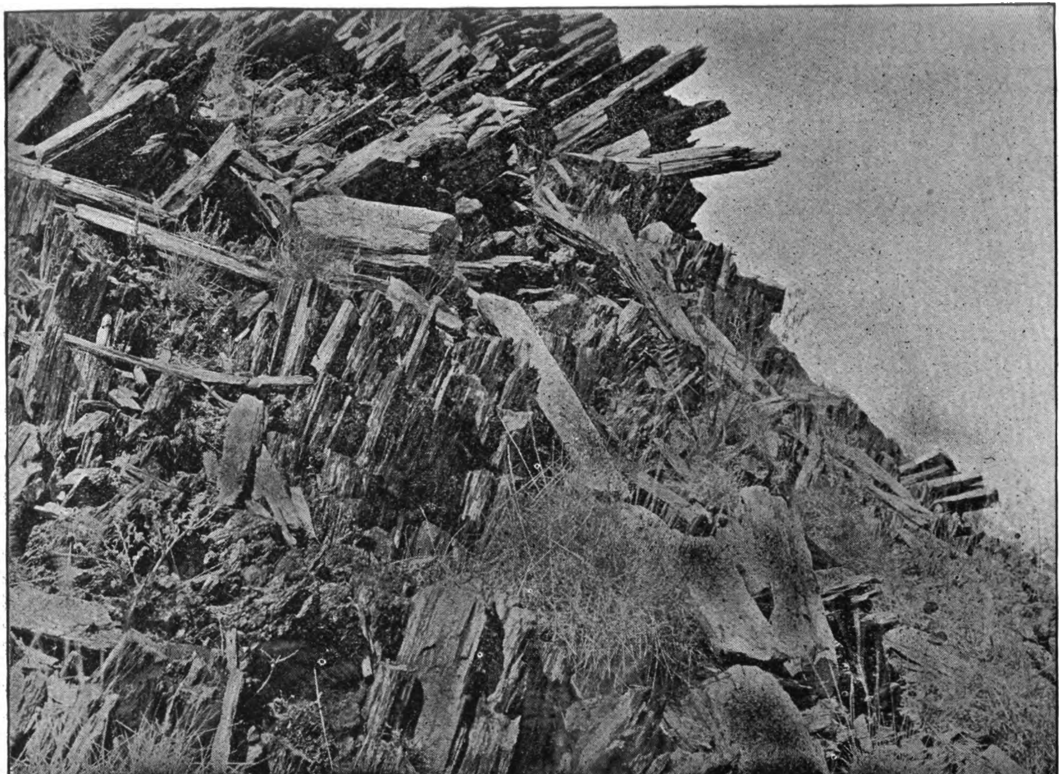
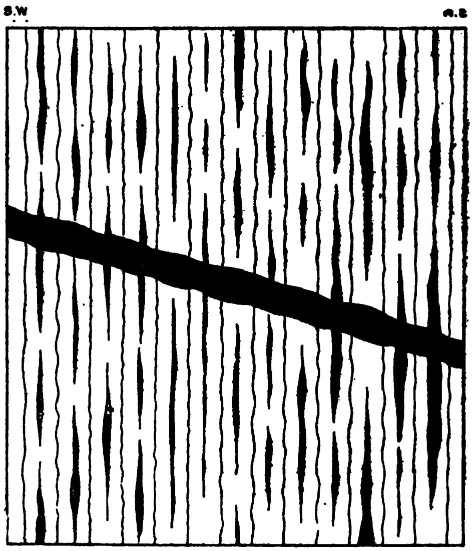


PHOTO.: S. J. BECHER.

Enlarged view of Sheeted Zone in country rock, Warrawoona, Pilbara Goldfield.

The faults which many of the reefs have undergone are referred to below under the heading of the Auriferous Deposits, and the position of those which can be actually observed and those the

Fig. 6.



SECTION ACROSS A COMPRESSION FRACTURE TRAVERSED BY A QUARTZ REEF. WARRAWOONA
PILBARA G.F

existence of which is inferred are shown upon the mining plans which form Plates IV., V., and VI.

Economic Geology.

Auriferous Deposits.

The auriferous deposits of Warrawoona are quartz reefs, which outcrop over a belt about six miles in length and about 20 chains in width.

There are no alluvial deposits of any extent anywhere within the limits of the area examined.

In addition to what may be called the main belt of Warrawoona, there are several minor outlying virtually isolated reefs, which have been worked in a more or less desultory fashion.

The position of all the quartz reefs has been laid down upon the Geological Map of Warrawoona (Plate III.) with such a degree of accuracy as the scale employed and a plane table survey would permit. No considerable body of ore, which is obvious to anyone making a fair and reasonable inspection of the surface, has been overlooked. The reefs exhibit, when viewed on the whole, a general

parallelism to the trend of the main structural features of the district. A careful examination of all the reefs, both on the surface and below ground, wherever such was possible, showed that they could be divided into two totally different types, which are sharply differentiated from each other.

The first type may, for convenience, be called the Normal or Fissure Vein Type, whilst the "Kidney" shaped lenticular quartz reefs of the second are locally spoken of as the "Leader."

Both types have been more or less opened up, and their relative importance as gold producers well established, as may be seen by a reference to the tables below.

Tables showing the yield of—

(*a*.) The Normal Quartz Reefs, and

(*b*.) The Leader Type of Deposits of Warrawoona.

The Normal Quartz Reefs.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	626·85	3,143·72	5·01
1899	1,194·75	3,679·56	3·08
1900	1,854·31	4,973·74	2·68
1901	355·75	874·25	2·45
1902	396·55	774·80	1·95
1903	429·85	1,080·64	2·51
1904	105·45	236·44	2·24
Total	**4,963·51**	**14,763·15**	**2·97**

The Leader Type of Deposit.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	78·55	276·75	3·52
1899	167·10	470·62	2·81
1900	87·40	314·45	3·59
1901	46·25	126·60	2·73
1902	49·70	147·26	2·96
1903	71·50	166·25	2·32
1904	49·00	125·38	2·55
Total	**549·50**	**1,627·31**	**2·94**

The data embodied in these two tables have been drawn up from the official statistics, but, of course, could not have been tabulated without a personal examination of the different reefs in the district. The figures demonstrate conclusively that whilst the

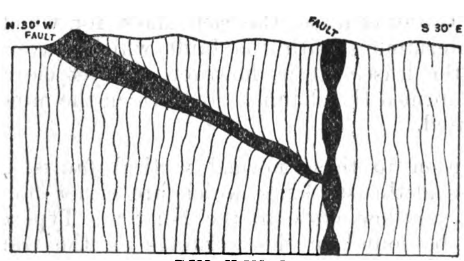
average value of the two types of deposit is about equal, it is, however, the normal quartz reefs that have, up to the present, been most extensively worked, and the reason is not far to seek.

The reefs of the Leader type are in every respect identical with those described * as forming the important deposits in the mining centre of Edjudina.

At Warrawoona, the "Leader," which forms a continuous band, so far as prospecting operations have shown, of about two and a half miles in length, occurs along a line of rupture, which is forcibly shown by the powerful slickensided surfaces exhibited almost everywhere underground. These faces are often coated with fine films of gold. The "reef" is represented by "kidney" or damper-shaped lenses of quartz which vary from a few inches in width to a foot or two in length along the vein. The interval between each lens of quartz naturally fluctuates within very wide limits. Sections are visible in some of the workings fully described on a later page, which show the "casing" of the lens to be quartz of a somewhat different type; cases of this kind, which are of frequent occurrence along the "Leader" line, seem to point to the quartz lenses being portions of a pre-existing quartz reef which has been shifted in segments, as it were, along a vertical line of dislocation. Until these quartzes have been submitted to microscopical examination it is impossible to determine whether they exhibit optically any signs of mechanical strain, as would be naturally expected.

There seem very strong grounds for believing that the reefs of the "Leader" type are of later formation than those of the true fissure veins. Fig. 7 shows a section of a fissure vein abruptly cut off by the "Leader."

FIG. 7.



SECTION OF THE REEFS IN THE OPEN CUT NEAR THE SOUTH EASTERN BOUNDARY OF G.M.L 308 WARRAWOONA PILBARA G. F.

From the very nature of the Leader it is naturally somewhat difficult to work, as the stopes must be kept within the narrowest possible limits, and merely the auriferous quartz lenses extracted.

* Notes on the country between Edjudina and Yundamindera, by A. Gibb Maitland, Bulletin 11. Perth: By Authority, 1903, pp. 14, *et seq.*

A feature of many of the normal reefs, notably those on the Bow Bells lease, is the folding which they have undergone; this characteristic is particularly well exemplified in the case of the Horseshoe vein, and is shown on the plan which forms Plate IV. It will be noticed that in those cases in which the folding has taken place, there is almost invariably a relatively large pocket of ore at the apex of the arch. The fold in the Horseshoe vein of the Bow Bells lease merely differs from the saddle reefs as depicted in many geological manuals in the fact that in this particular case the legs are horizontal. Mining operations, however, have hardly been carried sufficiently far to determine whether or not the apices of the folds contain any higher grade ore than what may be called the legs of the reef. The fact that rich chutes are known to prevail in intimate connection with the apices of the folds in other mining districts where the quartz reefs have been violently contorted is a circumstance which should commend itself to the attention of those engaged in the exploitation of the reefs in question. All the evidence available points to the fact that the folding of the reefs is the result of great lateral pressure acting upon the country rock after the formation of the reefs themselves. The folding and puckering of some of the quartz veins is well illustrated, even in many hand specimens, notably in the quartz schist [5789] on the Gauntlet East, G.M.L. 560, a micro-photograph of which forms Fig. b, Photograph "H." This lateral pressure has not only folded but has faulted many of the reefs. Wherever possible the faults which have any effective throw have been mapped and shown in both the geological and mining plans as well as in some cases in the sections by which they are accompanied. The high inclination of the majority of the veins is such as of course might permit of a considerable displacement without any marked effect upon the outcrop, hence many faults, unless disclosed during the course of mining operations, might easily escape detection. In the case of the main reef on the Gauntlet lease, the rich shoot for which the mine is famed is coterminous with the fault which traverses the whole breadth of the lease. It is, however, not yet clear whether this fault fissure formed the channel along which the mineralising solutions percolated.

In addition to these normal vertical faults, there are also reverse faults at thrust planes, which are either horizontal or are inclined at a very low angle to the horizon. Typical instances of these are to be found in the workings on the Gauntlet and the Klondyke-Boulder leases; in the first of these cases the actual horizontal displacement measures only a few inches.

The reefs of both types are composed of a hard, translucent and crystalline quartz, which, in addition to the gold, contains in subordinate quantities pyrites, chalcopyrite, limonite, malachite, ferruginous wad, and a muscovite mica which is partly chromiferous.

In some cases the gold can be seen contained in cavities, evidently left by the oxidation of pyrites.

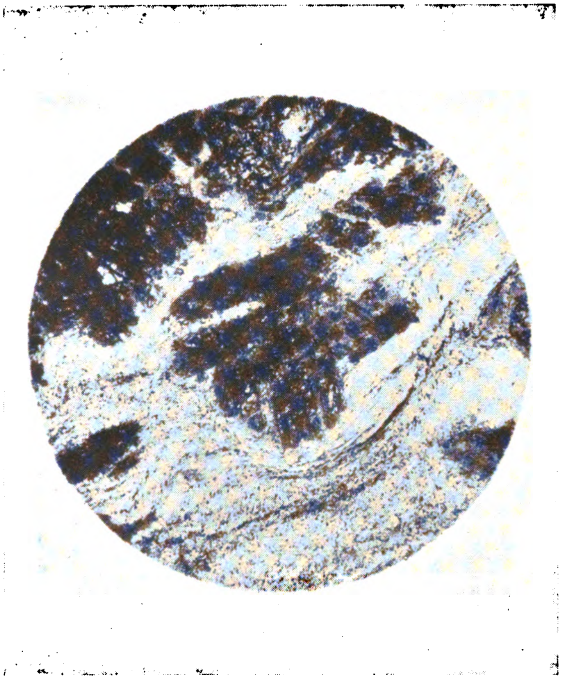


PHOTO.: E. S. SIMPSON.

Broken Crystals of Felspar (?) in sheared Felspar-Porphyry [5788], Warrawoona. Enlargement, 11 diameters.

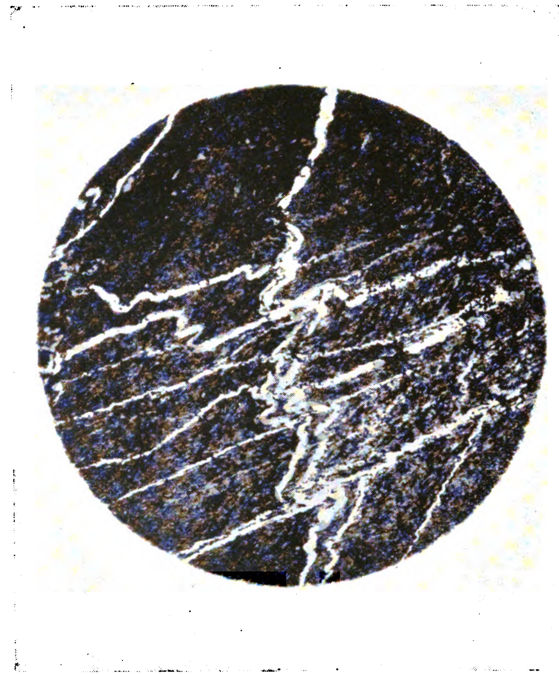


PHOTO.: E. S. SIMPSON.

Section of Quartz Schist [5789] showing contorted quartz laminæ in relation to stratification and cleavage foliation, G.M.L. 560, Warrawoona. Enlargement, 11 diameters.

Cases have been observed of the occurrence of calcite [5776] carrying a trace of gold; possibly the parent source of the calcite is to be looked for in the lime-soda felspars which enter into the composition of the greenstone and its allies, the country rock of many of the quartz reefs.

Although the total gold yield of Warrawoona has been 17,294·18ozs., recovered from the milling of 5,700·01 tons of ore, thus giving an average value of 3·03ozs. per ton, and many of the reefs have been opened up, these, however, have only been worked to very shallow depths.

All the mines which were open to inspection were visited, and full descriptions of them are given in the following pages. In the case of three properties—the Gauntlet, the Bow Bells, and the Klondyke Boulder, the reefs on which are instructive examples of the normal type as developed on the field—detailed surveys on a large scale of the various ore bodies, faults, etc., were made in the hope that they might in some measure furnish a guide as to the general behaviour of the reefs of this class in the locality. The result of these surveys has been embodied upon plans on the scale of 100 feet per inch accompanying the report, Plates IV., V., and VI.

For convenience of description, the mines and other workings are described in geographical sequence, commencing at the north-westernmost end of the field.

The Mines.

Princept, G.M.L. 517.—This is the most north-westerly lease on the Warrawoona Belt. The ground is now abandoned, and so far as may be seen very little work has been done upon the property. The surface of the lease is occupied by greenstone-schist of the prevailing type.

Near the north-western boundary of the lease is a shaft of unknown depth, sunk upon a vertical reef of about 12 inches in thickness. The reef has a general north-eastern and south-western strike. So far as may be judged by the stone lying at grass the quartz [5754] contains oxide of iron, green carbonate of copper, carbonate of iron, together with a little red copper oxide. An assay of a characteristic sample [5754] of the ore yielded in the Survey Laboratory gold at the rate of 1dwt. 15grs. per ton.

In addition to this there are two other reefs on the property, situated near the south-eastern boundary, and lying about 300 feet apart. The westernmost and most conspicuous of these forms the summit of a very prominent rise on the ground, and, as measured at the top, is from 20 to 25 feet in thickness. So far as may be seen the reef is vertical, and strikes a little to the west of north. About three feet to the west of this is a parallel reef of ice-like quartz, but of no horizontal extent. The eastern reef, about 300 feet distant, extends some considerable distance southwards, beyond the confines of the property.

The following table gives the yield of this property. The gold was entirely derived from the reef in shaft above mentioned:—

Table showing the Yield of the Princept Reef.

Year.	Ore crushed.	Gold therefrom.	Rate. per ton.
	tons.	ozs.	ozs.
1899	2·15	5·00	2·32

Cutty Sark, G.M.L. 521.—Messrs. Skogsberg and Svensen. This property is an old lease, the Cutty Sark, which has been resurveyed, and part of it is now held as Q.C. 142. The reef worked on this lease has an average strike of 305 degrees, and appears to be the same as that which enters the property near the north-east angle of the lease.

A vertical shaft 74 feet in depth has been sunk by the present holders of the property, and the stone stoped out from a depth of 60 feet; the reef is said to have been four feet in thickness. From the bottom of the shaft crosscuts six feet in length have been put in east and west respectively. Owing to the state of the country rock it is stated that work had to be abandoned at this level. At the date this property was visited, access could not be obtained below 33 feet from the surface; at this depth is a large body of quartz five to six feet thick, it is however merely a somewhat larger bulge on the reef than usual.

There are about 18 to 20 tons of quartz raised and awaiting crushing. The quartz at grass shows gold freely, it contains the red oxide, and the blue and green carbonates of copper in relatively small quantities, in addition to a little galena.

The only crushings from this reef were recorded in 1898 and 1904.

Table showing the Yield of the Cutty Sark Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	4·75	10·10	2·12
1904	31·30	49·00	1·56
Total	**36·05**	**59·10**	**1·64**

Tom Thumb, Q.C. 128 (141).—Trangmar. This property was originally embraced within the boundaries of G.M.L. 519, the Carnoustie.

A good deal of work must have been done upon this property by the previous owners of the ground, but most of these workings are inaccessible at the present time.

A vertical shaft 94 feet in depth has been sunk through almost vertical beds of chlorite schist [5756].

At 65 feet is a level, which has been put in along the strike of the country for a distance of 40 feet to the west. The face of the drive connects with the old workings, the end of the rich chute being at this point, and the stone, merely thin lenticular veins along the foliæ, being stoped out to the surface from the westernmost old shaft.

The quartz lenticules, of a totally different type to those occurring in Kopcke's leader, are said to attain a thickness of 12 inches in places. At the foot of the main shaft a quartz reef was met with and a fairly large body of water was encountered, at the point at which the stone was first intersected. The water is standing in the shaft at 85 feet from the surface. From stone shown to me, it appears that the quartz lenticules must be very rich in places.

Table showing the Yield of the Tom Thumb Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1903*	34·40	155·57	4·52
1904	2·15	9·09	4·22
Total	**36·55**	**164·66**	**4·50**

* Previous to 1903 the yield was included under the heading of Sundry Claims. In 1898, however, the official statistics show that 45·40 tons of ore crushed from the Carnoustie reef yielded 178·11ozs., or at the rate of 3·92ozs. per ton. This, however, in all probability was obtained from the reef outcropping just outside the north-east angle of the claim, as shown in the Geological Sketch Map of Warrawoona.

Golden Gate, G.M.L. 607 (now Q.C. 137).—The unsurveyed quartz claim, 137, originally embraced by the Golden Gate Lease, G.M.L. 607, lies some little distance to the south of the Tom Thumb. The workings, however, are inaccessible; the main shaft is reputed to have reached a depth of 76 feet, and the reef stated to have consisted of lenticular quartz veins occurring along the planes of foliation of the talc-chlorite schist [5755].

Table showing the Yield of the Golden Gate Reef.

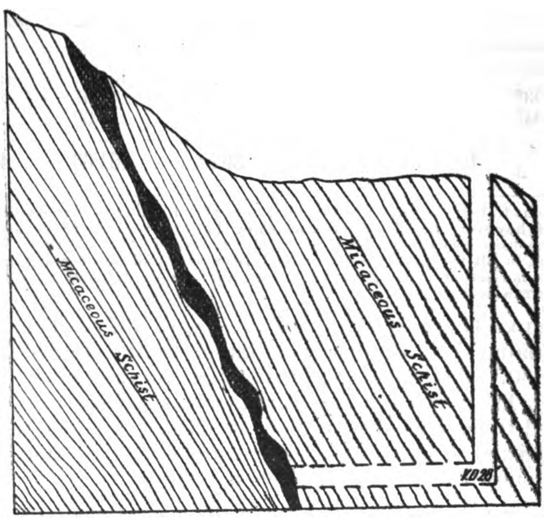
Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1901...	6·00	16·40 *6·00	2·73
1902...	13·00	29·10	2·24
1903...	40·45	73·00	1·80
Total	**59·45**	**118·50** ***6·00**	**1·99**

* Dollied and Specimens.

Seven Dials, G.M.L. 605.—The Seven Dials property, now abandoned, lies at the north-western extremity of what may be called the Bow Bells-Gauntlet Zone, as may be seen by an inspection of the Geological Sketch Map of Warrawoona. (Plate III.)

The reef prospected enters the property near the north-western boundary, and, after a somewhat sinuous course, leaves it by the south-eastern boundary, not far from the north-east angle of the lease. So far as may be seen in an opencut on the surface, the reef underlays to the north-east at 65 degrees, and varies from two to three feet in thickness. The reef appears to be somewhat faulted along the outcrop, though the horizontal displacement is not more than three or four feet in each case. A vertical shaft (Fig. 8), 28 feet in depth, has been sunk at a point 34 feet north-east from the outcrop. The shaft has been carried down through a narrow belt of a fine micaceous schist.

Fig. 8.



SECTION ACROSS THE SEVEN DIALS REEF G.M.L.605 WARRAWOONA
PILBARA G.F

Chance, G.M.L. 534.—This lease, now abandoned, occurs a few feet to the north-west of G.M.L. 531.

Work has been concentrated upon a somewhat similar deposit to that occurring in G.M.L. 531. At the outcrop the section across the vein from west to east is as follows:—Quartz, six inches; formation, eight inches; quartz, 12 inches; formation, 12 inches; quartz, three feet six inches. An underlay shaft has been put down to an unknown depth, but being inaccessible, no particulars as to the nature and behaviour of the reef underground are available.

The quartz [5769] is almost pure white, and contains oxide of iron, small quantities of green carbonate of copper, and chalcedony.

Lying in the vacant triangular piece of ground between this lease and G.M.L. 531 is an underlay shaft, which has been put down to an unknown depth, upon a thin vein of quartz underlying northwards. Workings along the outcrop further down the hill show the vein to attain a maximum thickness of 12 inches.

The returns of a small crushing in the year 1898 are shown in the table below.

Table showing the Yield of the Chance Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	4·00	8·35	2·08

May-be, G.M.L. 531.—This lease is abandoned, and no work had evidently been done upon it for some considerable time past. As may be seen by an inspection of the geological sketch map, it will be noticed that the northern portion of the property is traversed by the main laminated quartz vein, which forms what may be called the backbone of Warrawoona; this quartz vein has been traversed by three faults which have had the effect of shifting the outcrop a few feet in each case. All the work on the lease centred on the quartz reefs occurring on the south side of the laminated quartz vein. On the summit of a hill near the south-west angle of the lease is an open cut, 20 feet in length, exposing about an inch of quartz encased in a banded (partly silicified) greenstone [5768], the foliation planes of which underlie at an angle of 60 degrees northerly. The quartz leader lies along a compression fracture, which from its geological position may represent the north-western extension of Kopcke's leader.

Bow Bells Block No. 1, G.M.L. 524.—This is an old abandoned lease adjoining G.M.L. 523 on the north-west; it embraces a narrow strip of the northern portion of Bow Bells No. 1 West (*q.v.*). A few tons of stone have been crushed from this lease in 1898, as shown in the table; it is probable that this stone was raised from the reef in the inaccessible vertical shaft, of which mention is made in the description of the reefs on G.M.L. 593.

Table showing the Yield of the Bow Bells Block No. 1 Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	12·00	10·50	·87

Bow Bells No. 1 West, G.M.L. 593.—An abandoned 24-acre lease adjoining the Bow Bells on the north-west. As may be seen by an inspection of the geological map, there are seven quartz reefs traversing the lease in addition to the main laminated quartz vein. The principal work has been done upon a reef outcropping near the northern boundary of the lease. A vertical shaft, now filled up, had been put down to an unknown depth on the slope of the northern wall of the valley, traversing the ground, and connects with the surface lower down by a tunnel about 100 feet in length, driven on a bearing of 35 degrees. The face of the tunnel is filled with *débris* falling down the shaft, so that nothing whatever can be seen of the reef. The mouth of the vertical shaft shows a good solid body of quartz, varying from two to four feet in thickness. This stone in all probability represents the continuation of the large reef outcropping to the north of main shaft on the Bow Bells lease, distant about 400 feet. At the mouth of the tunnel is a heap of quartz [5770] showing free gold, in addition to muscovite, which is partly chromiferous and partly stained by limonite, iron pyrites, and chalcopyrite.

Another reef outcropping 18 feet north of the laminated quartz vein, forming the southern wall of the valley. The shaft is inaccessible, but as measured to the surface of the water at present standing in it, is at least 32 feet deep.

A little stone has been raised, and now lies at the mouth of the shaft. It contains [5771] muscovite, which is partly chromiferous, ferruginous wad, and limonite. The reef varies from one to three feet in thickness, and has such a strike as would carry it into the laminated quartz vein some distance to the west.

Bow Bells, G.M.L. 505.—The Bow Bells lease comprises an area of 12 acres, and was originally taken up by Messrs. Royer, Barnes, and Burroughs in the year 1898; it eventually passed into the hands of the present holders, The British Exploration Company of Australia, in 1901.

The lease, as may be seen by the Geological Sketch Map of Warrawoona, lies in the same zone as that which embraces the Gauntlet Mine, G.M.L. 483, from which it is distant about 100 chains to the north-west. The surface of the lease is occupied by greenstone schists and allied rocks, and the southern boundary of the property is traversed by the band of laminated quartz, which extends across the lease from end to end.

As shown by the large scale plan of the mine (Plate IV.), there are seven reefs upon the property.

The Northern Reef (No. 3 shaft), extends along the surface for a distance of about 80 feet, and underlies at a high angle to the north-east; the thickness of the reef as showing at the surface is

12 inches. The shaft by which the reef is worked is 39·63 feet above the level of the main (or Horseshoe) shaft, and has been carried down to a depth of 45 feet 9 inches. The shaft was inaccessible, but I was informed by the Manager (Mr. Hanemann) that at the bottom the reef proved to be small and poor. At a point about 50 feet north of the shaft, and along the outcrop of the same reef, is a shallow shaft, showing about 12 inches of quartz. No. 2 tunnel, 1·08 feet above the main shaft and 70 feet from it, was started with the object of intersecting the reef in No. 3 shaft, but after being carried in 8 or 10 feet, through country rock, it was apparently abandoned, and is now used as a store.

What may be called the *Horseshoe Reef* is worked from the main shaft, which has been sunk at the most convenient spot in the fork of the reef. The northernmost leg of the reef, as may be seen by the plan of the reefs (Plate IV.) can be followed for a distance of about 260 feet northwards, at which point it gradually tapers out to a thin vein of quartz, considerably less than an inch in thickness. At the bend of the horseshoe, the reef is about five feet in thickness. The southern leg of the reef can be followed, with a varying thickness, traversing No. 2 shaft, for a distance of about 150 feet, to a point at which it turns southerly, continuing on that course for a further distance of 50 feet, whence it gradually disappears. The main shaft, which has been carried down 106 feet 2 inches vertically, intersects the southern leg of the reef at No. 1 level, put in at a depth of 91 feet 6 inches; this reef is about three feet in thickness. The northern leg of the reef is represented by the 12 inches of quartz, intersected in the northern drive at a point about 40 feet from the shaft. An eastern drive about 50 feet in length has been put in practically along the country rock forming the footwall side of the reef. A narrow quartz vein, however, occupied the centre of the drive, and may possibly represent the small vein showing on the surface, for about 30 feet west from the mouth of No. 2 shaft. The eastern drive has been carried south on a bearing of 171 degrees for a distance of 18 feet, through massive greenstone. It is contemplated continuing this with the object of intersecting the rich chute worked in the reef in No. 1 shaft, and hauling all the stone to be milled from the main shaft.

The Tunnel Workings.—The workings at No. 1 tunnel and No. 1 shaft, are the most extensive, and appear to be the most important on the property. The mouth of the tunnel is 18·94 feet above the level of the main shaft, and has been carried in for a distance of 85 feet from the mouth to a point at which it intersects the reef, followed down from the surface in the workings from No. 1 shaft. Forty-five feet back from the face of the tunnel is a quartz reef two feet six inches in thickness, which in all probability represents the northern leg of the main reef. On the surface at the mouth of No. 1 shaft the two legs of the reef are 20 feet apart, whilst in the tunnel, 59 feet vertically below, they are 40 feet apart,

Twenty-three feet from the mouth of the tunnel is a small reef of six inches underlying to the north-east, and which in all probability represents the feather edge of the middle or lens-shaped mass of quartz (the Middle Reef) shown on the plan (Plate IV.) as lying midway between the Main and the Horseshoe Reefs. From the face of the tunnel, drives have been carried north and south for distances of 60 and 60 feet respectively; and for a length of 40 feet northwards from the face of the tunnel the reef has been stoped out to the surface, and has produced, up to the end of 1903, 483·70 tons of quartz, officially recorded as yielding 855·69ozs. of gold, or at the rate of 1·76ozs. per ton. The reef can be followed with more or less interruption northwards, but to the southwards it appears to be represented by a mere thread of quartz. At a point about 60 feet south from the tunnel a crosscut has been put in 40 feet south from the drive, through more or less foliated greenstone, with thin films and threads of quartz along the foliation planes. At the face of the crosscut the laminated quartz vein has been pierced and proved to be 10 feet in thickness, with an underlie of 65 degrees to the north-east. There does not seem to be any distinct line of demarcation between the country rock and the vein; the whole appearance suggesting a gradual replacement of the original rock along lines of maximum compression or foliation. On the footwall side of the vein is a body of quartz of as yet unknown thickness; in its general appearance, this quartz closely resembles some of the auriferous quartz of other portions of the field, and on that account seems worthy of being, at least, opened out and prospected. From the foot of the main shaft, and at the face of the tunnel, a winze, No. 1, has been carried down on the reef 77 feet 6 inches; this winze, which was inaccessible below 24 feet from the drive, has been put down on the footwall side of the chute followed above. No. 2 winze, however, about 20 feet to the north has been put down in the centre of the chute, and carried down 83 feet. The chute, which underlies north, leaves the winze at about 40 feet. The reef in this winze is very strong, and in places large, attaining as much as eight to 10 feet in thickness; at the foot of the winze, owing to a large bulge in the reef, its exact width had not been ascertained at the time of my visit. An intermediate level connects the two winzes at 24 feet six inches below the drive; about 200 tons of ore have been taken out above, and now await crushing. The quartz [**5782**] has a very ice-like appearance, and contains small scales of sericitic (?) mica, and irregular patches of serpentine. A sample of it assayed gold at the rate 1dwt. per ton. It is contemplated intersecting this chute from No. 1 level in the main (Horseshoe) shaft by a crosscut put in from the face of the eastern drive, as may be seen in the section (Plate IV.). The width of the chute appears to be about 35 or 40 feet.

There are many points of similarity between the geology and economic features of this property and the Gauntlet. The ore deposits in each case belong to one and the same type, and both occur in the same mineral zone.

So far as may be seen by a careful inspection of the surface it appears as though a considerable amount of faulting has gone on. The inferred position of these faults has been indicated upon the plan which forms Plate IV.

The following table gives the yield of the reefs on this property:—

Table showing the Yield of the Bow Bells Reefs.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	55·00	152·40	2·77
1899	183·00	342·30	1·87
1900	104·20	175·29	1·68
1901	*Nil*	*Nil*	...
1902	141·50	185·70	1·31
1903	*Nil*	*Nil*	...
1904	*Nil*	*Nil*	...
Total	**483·70**	**855·69**	**1·76**

Adjoining the Bow Bells Lease on the north, and on the ground taken up for a battery site, is another very conspicuous quartz reef. This bold reef, which outcrops at about 40 feet from the boundary of the Bow Bells lease, measures about 20 feet in its widest part, and can be followed along the surface for about 484 feet. The eastern end of the reef bifurcates, and both horns of the fork gradually dwindle out to threads of quartz. The western end of the reef is about 50 feet from the north-west angle of G.M.L. 505.

Great Western, G.M.L. 502.—An abandoned 12-acre lease lying in the main belt some distance to the south-east of the Bow Bells. Some desultory work has been done upon a well defined reef, varying from 1 to 5 feet in thickness. The reef occurs in a very much crushed greenstone. The quartz in places contains veins and eyes of banded bright green serpentine [5772] which present every appearance of having been produced by shearing. The reef is in all probability along (or parallel to) the same line of fracture which carries the Main Bow Bells Reef. The quartz is of a white colour, and practically destitute of any other mineral, except a very little pyrites, closely associated with the green serpentine previously referred to. A parallel reef occurs near

the south-eastern angle of the lease, but no work has been done upon it.

In 1898, when the property was visited by the then Inspector of Mines, Mr. Gladstone, about 100 tons of quartz had been raised from the first lease, and awaited treatment. No separate crushings from this lease appear in the returns; any returns are in all probability included under the heading of the yield from sundry claims.

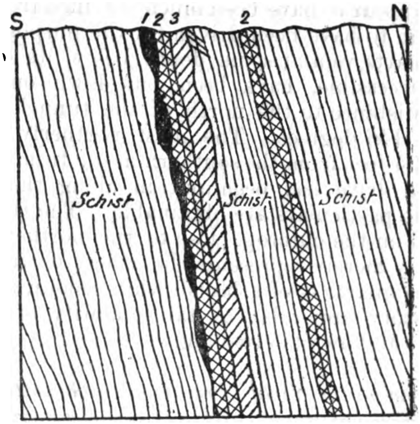
A tunnel had been put in 55 feet on a bearing of 223 degrees, on the vacant ground lying between this lease and that adjoining G.M.L. 595; the tunnel had been carried through decomposed schist underlying to the north-east. At about 35 feet from the mouth of the tunnel there is about from six to eight inches of quartz exposed, which represents the continuation of the reef opened up in G.M.L. 502; the face of the tunnel exposes a thin vein of quartz of from two to three inches in thickness.

Gauntlet No. 3 Nor'-West, G.M.L. 595 (*late* Gift).—This abandoned 24-acre lease is traversed by two principal reefs which have been worked at one time or another by three shafts. The most northerly shaft, which is inaccessible, has been sunk to a depth of 15 feet on a reef having a general strike of 107 degrees, with a high underlay to the north. A little stone has been taken out from the reef, which, judging from the ore at grass, had a maximum thickness of 12 inches. So far as may be seen in the sides of the shaft the reef is represented by three or four quartz veins about a couple of inches in thickness. The same reef has been opened up at intervals along the outcrop for a distance of about 100 feet eastwards from the shaft; in one place the reef measures from two to three feet across. A very little stone has been raised and is now stacked; the quartz is of a pure white colour and contains small quantities of iron ore; a sample [**5774**] of it assayed gold at the rate of 1dwt. 15grs. per ton.

The principal workings on the lease, however, are on the vein lying to the south-west of the laminated quartz vein and about 148 feet from it. Two shafts, 94 feet apart, have been put down upon the vein. The south-eastern shaft (No. 2) is inaccessible, and no information is available; the vein has been opened up along the surface for a distance of 38 feet along the outcrop south-east from this shaft, but owing to the condition of the workings little is to be seen of it. No. 1, or the westernmost shaft, is distant 94 feet from No. 2, and the stone has been worked right to the surface between the two but from what depth cannot be ascertained. This shaft, the depth of which is unknown, has water standing in it to about 35 feet from the surface, and is now used as a well. Owing to the influx of water, it is asserted, the property had to be abandoned.

Fig. 9 gives a section across the reef, which lies along a line of fault, the hanging wall of which is marked by a somewhat puckered and greatly slickensided vein of quartz.

FIG. 9.



SECTION ACROSS THE GIFT REEF G.M.L. 595.
WARRAWOONA PILBARA G.F
1 Gift Reef along line of Fault 2 White Quartz 3 Black Quartz,

This vein is the continuation of Kopcke's Leader.

The following table gives the yield of this reef so far as can be ascertained from official data.

Table showing the Yield of the Gift Reef.

Year.	Ore Crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	11·80	23·50	1·99
1899	32·25	50·00	1·55
Totals	**44·05**	**73·50**	**1·66**

GOLDEN GAUNTLET, G.M.L., 506.—This lease adjoins the Gift, on the east; a fair amount of work has been done at the north-west end of the property, on a reef which occurs, as may be seen by an inspection of the geological map, in close proximity to where the main laminated quartz vein is traversed by the greenstone dyke [**5773**].

A tunnel has been put into the face of the hill on a bearing of 240 degrees, for a distance of about 75 feet. At 34 feet from the mouth of the tunnel, the laminated quartz vein has been met with,

and passed through at 47 feet, giving a thickness of 13 feet; the vein underlays to the north-east at 85 degrees. At the face of the tunnel the decomposed rock is much less foliated than that exposed in the rest of the tunnel, thus indicating a gradual decrease in foliation as one approaches, and receded from the quartz vein. There does not appear to have been much obtained from this tunnel, which would seem to have been driven for the purpose of exploring the laminated quartz vein at some depth below its outcrop. Two shafts, now inaccessible, have been put down on a large reef situated a little distance to the north of the tunnel which has an average strike of 146 degrees. The most northerly shaft, 35 feet deep, is distant 95 feet from the southernmost; from the foot of the northern shaft a drive has been put in along the reef in both directions, but no particulars are obtainable. The thickness of the reef as measured on the outcrop, close to the northern shaft, is 20 feet, and probably merely represents the widest portion of a bulge in the reef. The quartz is of a bluish white colour, and appears to contain no accessory minerals. A fair quantity of outcrop stone has been stacked and awaits crushing.

Table showing the Yield of the Golden Gauntlet Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1899	3·00	4·60	1·53

Gauntlet, G.M.L. 483.—The Gauntlet Lease was originally taken up in the year, 1898, by Mr. R. H. Mackenzie; it comprises an area of 12 acres, and has been responsible for a yield of 3,693ozs. of gold, or 2·86ozs. for every ton of ore milled up to the close of 1903.

The surface of the lease is occupied by greenstone schists and allied rocks, whilst skirting the southern boundary is a continuous and conspicuous band of laminated quartz about 10 feet in thickness. The foliated greenstone contains large crystals of iron ore, identical with those weathering out of the massive variety.

There are practically four principal reefs, *i.e.*, reefs upon which any work has been done, on the ground, the longest having a length along the outcrop of at least 400 feet, and the shortest about 100 feet (Plate V.). When the position of the reefs is accurately laid down upon a plan, it is noticed that they exhibit, with minor variations, a rude parallelism, the general strike being north-west and south-east, which coincides with that of the foliation and dominant structural features of the district. About 45 feet north of the band of laminated quartz is a fairly continuous quartz reef outcropping for about 500 feet from the north-western boundary of the property. This reef attains a thickness of about two feet in

places, though as a rule very thin, it is perhaps the one which exhibits the greatest linear persistence on the lease.

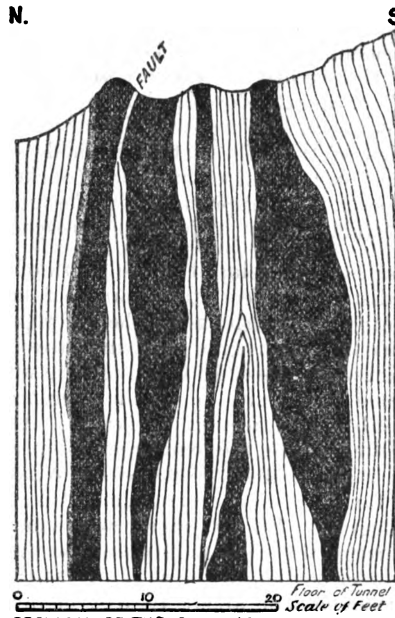
The South Reef.—The South Reef, which has been opened up by means of a tunnel and several small open-works, can be traced across the surface for about 140 feet. The tunnel has been driven about 31 feet in a southerly direction; at its mouth the reef, merely an exceptionally large lenticular mass of quartz, the maximum thickness of which measures 2 feet 3 inches, has been exposed. The country rock in the tunnel is decomposed schist, with small lenticular "eyes" of quartz developed along shear planes. The open-works on this line merely expose a similar succession of quartz lenticules. In view of the fact that their mode of occurrence is identical with those on that important line, Kopcke's Leader (*q.v.*), and that they are said to be appreciably auriferous, this line would seem to merit a certain amount of judicious prospecting.

The Main Reef.—As developed to the south of the main shaft, from which it is distant 40 feet, the main reef has a continuous outcrop of 132 feet; the eastern end of the outcrop originates as a mere thread of quartz, which gradually increases in size until it reaches a maximum thickness of 10 feet. At the western extremity, where it is truncated by a fault, to which reference will be made later, the reef is about six feet in thickness. As shown in the large open cut at the surface, the main reef is intersected by two faults, making an angle of about 55 degrees. What may be called the main or cross fault has a general strike of 163 degrees, and the strike fault, 110 degrees. Fig. 10 shows what may be called the "compound" nature of the reef as exposed in the open cut, the tunnel, and the lowest portion of the workings at the present time. There is a total thickness of about 16 feet of quartz exposed in the open cut, 14 feet in the tunnel, and about 12 feet at the bottom workings. The main reef has been opened up by means of a vertical shaft (the main shaft) 126 feet 6 inches in depth and a tunnel 168 feet in length. The shaft, which is eight feet by four feet, intersected the reef at 101 feet from the surface, and had been carried down through a foliated green rock. East and west drives, 95 and 201 feet respectively, have been put in at 101 feet; at 116 feet in the shaft is water level, of which there is 10 feet standing.

The tunnel has been put in at a point 85 feet west of the main shaft, about 20 feet vertically below it, and intersects the bottom of the open cut previously alluded to. At about 32 feet from the mouth of the tunnel a winze has been carried down along the plane of the fault to the western end of the drive from the main shaft 87 feet vertically below the level of the floor of the tunnel. Fig. 10 is a section of the reefs, etc., seen in the tunnel at the foot of the open-cut. From this point the tunnel has been carried through foliated country rock, with quartz leaders; on nearing the face of the tunnel the schist becomes much more siliceous, suggesting the proximity of the laminated quartz vein which occupies the surface of the southern boundary of the lease.

The whole of the stone has been taken out from the floor of the tunnel to the surface, 38 feet vertically above it, and from this spot practically the whole of the 3,693ozs. of gold, as shown in the return

Fig. 10.



SECTION OF THE GAUNTLET MAIN REEF
WARRAWOONA PILBARA G.F

appended, was obtained. From what can be seen in this portion of the mine, it appears that the ore chute lies in, or in close proximity to, the acute angle formed by the two principal faults alluded to previously; the positions of these are delineated on the plan of the reefs and underground workings (Plate V.).

The main reef has been met with in the west level, opened out from the end of the crosscut, 38 feet in length, south from the main shaft. The reef first makes its appearance as a mere thread of quartz at a point in the drive 23 feet east from the centre of the crosscut; at this spot it measures from six to eight inches in thickness, and gradually increases towards the face. At one point in the drive the reef measures fully eight feet of solid quartz; powerfully slickensided faces on the foot-wall demonstrate that the reef occurs along a line of fault. The slickensides hade in the same direction as the underlay of the reef, to the northwards. The end of this level intersects the winze from the tunnel overhead, and has been carried down 16 feet 6

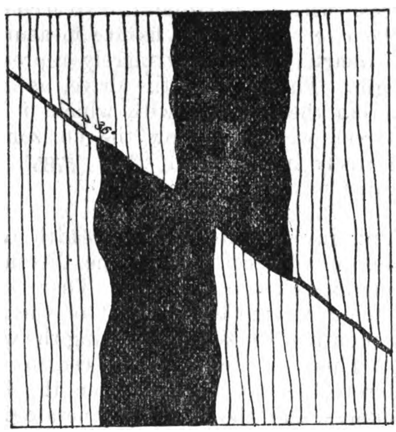
inches from the floor of the drive. At the mouth of the winze the main reef measures three feet nine inches; whilst at its foot it is four feet eight inches, with a thin band of schist. Thirteen feet from the north face is a second reef of 24 inches, separated from a third of three feet by ten inches of schist. This section agrees in the main with that occurring in the tunnel at the foot of the open cut, in that there are three bodies of quartz separated by varying thicknesses of schist. The main fault leaves the south drive at a point 26 feet from the foot of the winze on the eastern wall, and does not appear to have been followed. The drive is continued about 22 feet from this point on the western wall of the fault through schist containing thin ribbons of quartz and small cubical crystals of pyrites. An important feature in this winze is an almost horizontal fault, or thrust plane, hading to the north at about five degrees, with a horizontal displacement of from 12 to 18 inches to the rise. The fault fissure measures less than six inches filled with quartz, which may merely represent a flat leader of secondary origin. The floor of the drive, as ascertained by a trench put in across the mullock with which it had been filled, showed that the reef occurred below the horizontal fault. Free gold is showing freely in the solid stone [5785]. The bottom of the winze is at water level.

The main fault traverses the whole breadth of the lease, and abruptly truncates a bold reef lying some distance north of the north-eastern boundary of the property. There seems to be good reason to regard the reef lying to the west of the fault, and about 120 feet from the mouth of the tunnel, as being the western extension of the main reef. This reef lies near the centre of the lease, and makes a bold outcrop of nearly 300 feet in length; it is, in places, of considerable thickness, and the general mineralogical character of the quartz agrees very closely with that which forms the main reef itself. This possible extension of the main reef, more especially where it is truncated by the fault, has not been prospected. I understand appreciable quantities of gold have been obtained there. There are two other smaller reefs, shown on the plan (Plate V.), in close proximity to this one; these also have not been prospected.

The East Reef.—The East Reef, as showing on the surface, has an outcrop of 275 feet in length, and a width of about eight feet in its widest part; both ends of the outcrop are represented by thin threads of quartz. The reef has been opened up both from the main shaft and the east shaft, which is 95 feet in vertical depth, and has been sunk on the reef the whole way. The reef makes its appearance in the eastern drive from the main shaft at a point about 50 or 60 feet from the eastern shaft, where it is represented by a thread of quartz, which gradually increases in thickness until it occupies the full width of the roof of the drive, and attains a maximum thickness of eight feet. There is at this level a blank space of about 50 feet between the end of the main and the east reef, though at the surface the

extent of dead ground is not so great. At the surface the two extremities of the reef are about 14 feet apart in a direction at right angles to the underlay, and, underground, at 100 feet vertically below, the distance is barely 10 feet. Beyond the stone taken out of this reef in sinking the shaft, driving the level, and a little from the small open cut on the surface, no further work has been done. The foot of the eastern shaft also exposes a reverse fault, Fig. 11, which has a throw of about two feet, and a hade of 35 degrees to north 75 degrees east.* The quartz exposed in the shaft averages about three feet in thickness.

FIG. 11.



SECTION OF A REVERSE FAULT IN THE GAUNTLET MAIN REEF AT No. 1 LEVEL. WARRAWOONA PILBARA GF

The North Reef.—The North Reef lies on the opposite side of the valley which traverses the central portion of the Gauntlet lease longitudinally, at a considerable elevation above the lowest portion of the ground. The reef outcrops at an average distance of about 90 feet from the north-eastern boundary of the lease, and occupies the surface for a distance of about 440 feet. The north-western end of the outcrop of the reef bifurcates, with an extension of the reef to the north-east of about 40 feet. At this point the stone, which is about four feet thick, is abruptly truncated by a fault, which also cuts off a larger reef, 160 feet in length, at a point about 200 feet to the south-east. This latter reef makes a very pronounced outcrop, and is of considerable thickness. A vertical shaft, 29 feet deep, has been sunk at a point near the thickest portion of the north reef, but beyond this no other work has been done upon it.

* By an error Fig. 11 gives the section as being in the main reef, whereas it should be the east reef.

The following table gives the yield of this lease, the gold having been entirely derived from the stone occurring at the faulted extremity of the main reef:—

Table showing the Yield of the Gauntlet Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	106·20	430·90	4·05
1899	150·10	736·15	4·90
1900	872·00	2,269·00	2·60
1901	136·50	238·05	1·74
1902	24·50	19·45	·79
1903	*Nil*	*Nil*	*Nil*
Total	**1,289·30**	**3,693·55**	**2·86**

Rangatira, G.M.L. 491.—An abandoned lease, adjoining the Gauntlet, on the south. The property is traversed by two reefs, upon which a little desultory work has been done. A small crushing, particulars of which are given below, has been obtained from this lease.

Table showing the Yield of the Rangatira Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1899	**8·50**	**5·15**	**·60**

Gauntlet East, G.M.L. 560.—The north-western boundary of this lease is traversed by what may be the faulted extension of the East Reef of the Gauntlet. An inaccessible vertical shaft has been sunk upon it, but nothing can be seen of the reef and its behaviour underground. To the eastward and not far to the west of the Treble Event boundary, a tunnel 55 feet in length has been driven on a bearing of 296 degrees, through a fine-grained quartz schist [5789] traversed by a deposit of the leader type. Nothing, however, beyond this has been done on the property.

There do not appear to have been any crushings recorded from this lease, unless such are included in the yield of those from sundry claims.

Imperialist, G.M.L. 564.—The Imperialist reef lies about 400 feet to the south of what may be called the main reef series of Warrawoona. The reef can be followed more or less interruptedly along the surface for a distance of at least 2,200 feet south-east, and as may be seen by an inspection of the Geological Sketch Map (Plate III.), there seems to be good reason to believe that it may extend much further than this.

The Imperialist has been exploited by three principal shafts, all of which are situated near the western extremity of the outcrop. No work was being carried out at the date the property was visited and the main shaft had been dismantled.

The westernmost shaft (now filled in) is situated near the western extremity of the outcrop of the reef, which at this point strikes 101 degrees. Judging by the condition of the dump and the workings a fair amount of work must have been done from this shaft. Between this point and the Central shaft, 114 feet distant, the reef has been opened out at one or two places, and about 12 inches of quartz exposed. A considerable amount of work has obviously been done from the Central shaft; this shaft, which exposes from 6 to 12 inches of quartz, is inaccessible. The main shaft bears 97 degrees from the Central, and is 83 feet distant from it. Water stands in the shaft at 80 feet from the surface. The quartz lying at the mouth of the shaft contains fragments of serpentine [**5775**]—a sample of this quartz yielded, on assay in the Survey laboratory, gold at the rate of 1dwt. 15grs. per ton—and large veins of calcite [**5776**], some of which are 12 inches in thickness. The calcite yielded a minute trace of gold per ton. The country rock of the reef is [**5777**] a talc-chlorite schist. The quartz of the Imperialist, so far as may be judged by the stone in the dump, seems to be a replacement of the country rock.

Near the north-east angle of the lease is another parallel reef of from six to eight inches in thickness, upon which a fair amount of work has been done. The reef has been stoped out to the surface from a depth of 20 or 30 feet; the workings, however, are inaccessible. The country rock is schist of the prevailing type. The quartz is traversed by a small vein of calcite. There are three other more or less parallel reefs in the vicinity of the Imperialist, but no work appears to have been done upon any of them.

The following table gives the yield of the Imperialist reef:—

Table showing the Yield of the Imperialist Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1899	163·75	214·01	1·30
1900	367·50	389·20	1·05
1901	17·50	26·30	1·50
1902	*Nil*	*Nil*	...
1903	147·00	181·07	1·23
Totals	**695·75**	**810·58**	**1·16**

Treble Event, G.M.L. 573.—This six-acre lease adjoins the Dodger on the west. Two apparently deep shafts have been put down upon what appears to be the north-western extension of the

Dodger Reef. Nothing, however, can be seen of the reef at the present time. A small trial crushing, of a little over three tons, has been recorded from this reef in 1902, with the results as shown in the table below:—

Table showing the Yield of the Treble Event Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1902	**3·25**	**4·00**	**1·23**

Dodger, G.M.L. 587.—Two shafts have been sunk on a reef, which lies a short distance to the north of the laminated quartz vein, and parallel to it, but at the present time nothing can be seen of the nature of the reef and its behaviour underground.

Klondyke Boulder Block, G.M.L. 577.—No work has apparently been done upon this property, which was evidently taken up with the object of intersecting the Klondyke Boulder Group of reefs at depth on the underlie.

Princess of Alaska, G.M.L. 489.—This is an old abandoned lease which included within its boundaries the three leases 573, 587, and 577. Two small crushings have been recorded from this in 1898 and 1899, but there is, however, nothing to indicate at the present time whether the stone was obtained from the Treble Event, G.M.L. 573 (*q.v.*), or the Dodger, G.M.L. 587 (*q.v.*).

Table showing the Yield of the Princess of Alaska Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	11·00	33·56	3·05
1899	29·00	37·05	1·27
Total	**40·00**	**70·61**	**1·76**

Klondyke Boulder, G.M.L. 604 (late 476).—This 12-acre lease, which has turned out 2,356ozs. of gold, or at the rate of 2·40ozs. per ton of ore milled, was originally granted to Messrs. Hall and Cook in the year 1898, and was numbered 476. The lease was subsequently re-numbered 604 on its being conditionally surrendered in 1901.

A considerable amount of work has been done upon the property since it was first exploited, but at the date the locality was visited, the lease being under exemption and the main working

full of water, access underground could not be obtained; there appear to be no plans of the workings, hence no information as to the nature and behaviour of the reef below surface is available.

As may be seen by an inspection of the Geological Map (Plate III.), it will be noticed that the surface of the lease is occupied by greenstone schist; the north-eastern portion of the ground is traversed by a narrow but persistent band of very much sheared greenstone, which forms a very pronounced feature on the surface. This band lies about an average distance of 100 feet south of the conspicuous laminated quartz vein which traverses the field.

All the reefs lie to the south of the laminated quartz vein; they, however, do not occur in that zone which embraces the Bow Bells and the Gauntlet reefs. The Klondyke Boulder reefs present many features in common with those of the two properties mentioned above. The position of the reefs, etc., is shown on the plan which forms Plate VI.

There are two distinct types of ore deposits on the property, the most persistent being that which may be conveniently termed the leader, which trends generally north-west and south-east, and has an outcrop of not less than 650 feet; the second type being that of the main reef, which has a much more westerly trend than that of the leader.

The Leader has been opened up at six or seven places on the lease, but in only one spot (E) does any very serious attempt appear to have been made to exploit it. At this spot a vertical shaft had been put down on a shear plane underlying at a very high angle to the south-west. The shaft proved to be inaccessible; but from what could be seen on the south-eastern wall the reef consisted of eye-shaped masses of quartz encased in slickensided faces of older quartz, about three to four inches in thickness. There is every geological reason for believing that this reef is merely the north-western extension of Kopcke's leader (*q.v.*).

The Main Reef consists of a vein of quartz, having an outcrop measuring about 130 feet in length; it has been worked by means of two shafts, B and C. Shaft B measures 25 feet in depth, and from it is an open cut 83 feet in length, in which a somewhat tortuous quartz reef is exposed; little, however, is to be seen of it at the present time, though in one place there is about 12 inches of quartz exposed. At the south-west end of the open cut, and about three feet from the main reef and on the north side of it, is a large lenticular mass of bluish-white quartz several feet in thickness. Its position is shown on the plan of the reefs forming Plate VI. There seem good reasons for believing the main reef and this lenticular mass of quartz to be separated by a fault hading to the north. Between this lens and shaft E is another boomerang (kylie) shaped mass of quartz about 80 feet in length. Shaft C, 21 feet northwards from B, is also inaccessible. Water is standing in the shaft;

to the top of the water is 84 feet. About 55 feet north-west from the shaft B is another vertical shaft 44 (?) feet deep, sunk with the intention of working the small reef, shown on the plan, outcropping for about 50 feet, and lying a little distance to the south.

To the north-west is a tortuous reef, which occupies the surface for about 140 feet. The reef, which is well seen in the open cut, along its outcrop is traversed by two faults, as shown on the plan (Plate VI.). The southernmost fault is continuous in a south-easterly direction and probably extends as far as that which truncates the reef outcropping at A, referred to later on.

At A is a quartz reef of three feet ten inches in thickness and 70 feet in length, cut off by an almost north and south fault. This fault, which is exposed in a shallow shaft nine feet deep, underlies in a direction north 65 degrees east at an angle of 24 degrees. A section is given on Plate VI. showing this fault; it is, however, taken across the reef and not in the direction of the true dip. There seem good grounds for believing this to be a reverse fault.

The main shaft workings are inaccessible, hence there are no data as to the nature, thickness, and other cognate points of the reef.

The following table shows the yield of this property :—

Table showing the Yield of the Klondyke Boulder Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	90·45	379·14	4·19
1899	262·45	526·28	2·00
1900	253·71	436·55	1·72
1901	92·50	287·60	3·10
1902	81·05	159·65	1·97
1903	198·00	567·00	2·86
1904	38·00	94·71	2·49
Total	**1,016·16**	**2,450·93**	**2·41**

Wheel of Fortune, G.M.L. 611 (formerly G.M.L. 571, and Dawson City, G.M.L. 477).—There are two well-defined reefs on the property, both of which lie some distance to the north of the conspicuous laminated quartz vein which occupies the southern boundary of the lease. Several shafts have been put down, to depths not known to me, upon that well-defined quartz reef, which lies about 100 feet north of the laminated quartz vein. In August, 1898, Mr. Inspector Gladstone mentions the depths of three of these shafts as being, respectively, 50, 35, and 50 feet, the latter one

being on a reef three feet in thickness. The reef, as exposed at the surface, is of that bluish-white colour, which characterises the reefs of Bow Bells and Gauntlet types.

Some of the quartz [**5791**] contains quantities of the red oxide and the green carbonate of copper, together with films of sericitic mica and a little serpentine. A sample of the characteristic cupriferous variety [**5791**] assayed in the Survey laboratory: gold, 4dwts. 2grs. per ton, and copper 1·23 per cent. There have been four crushings recorded from this property, details of which are given in the table below:—

Table showing the Yield of the Wheel of Fortune Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	25·60	6·90	·27
1899	*Nil*	*Nil*	...
1900	96·50	99·95	1·03
1901	16·50	11·50	·70
1902	67·75	131·60	1·94
Totals	**206·35**	**249·95**	**1·21**

NELSON, G.M.L. 514.—A shallow shaft has been sunk upon a prominent east and west reef, situated near the north-west angle of the property, but very little work appears to have been done upon it. A small trial crushing was obtained from this reef in the year 1898, with the result as shown in the table.

Table showing the Yield of the Nelson Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	**1·25**	**5·29**	**4·23**

KLONDYKE No. 1 WEST, G.M.L. 578 (formerly Klondyke No. 1, G.M.L. 474).—The leader, lying to the south of the laminated quartz vein, traverses the whole length of the property, and all the work done on the lease appears to have been concentrated on it. Two inaccessible shafts have been put down on the leader, but at the present time there is nothing to be seen of anything underground.

Writing in 1898 Mr. Inspector Gladstone mentioned that the one shaft then sunk had attained a depth of 60 feet, and exposed "a rich leader with three-feet lode formation."

The official returns shown in the table below demonstrate that the leader was rich, crushing nearly at the rate of $4\frac{1}{2}$ozs. per ton.

Table showing the Yield of the Klondyke No. 1 West Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	5·00	37·77	7·55
1899	14·95	63·20	4·22
1900	23·05	88·70	3·84
Total	**43·00**	**189·67**	**4·41**

Klondyke Block, G.M.L. 507.—This 18-acre lease lies north of, and adjoins the Klondyke property. Six well-defined reefs traverse a portion of the property, but no serious work seems to have been done upon any of them. Two of the reefs are of the bluish colour which characterises the quartz of the Bow Bells and Gauntlet reefs.

A crushing of 37 tons has been recorded in the year 1898, the yield of which being shown in the table below :—

Table showing the Yield of the Klondyke Block Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	**37·00**	**764·00**	**20·65**

Klondyke, G.M.L. 473 (now called the Klondyke Queen, G.M.L. 627.)—The Klondyke Lease comprises an area of six acres. and was originally taken up by Messrs. Poutt and Corboy in the year 1898; it eventually passed into the hands of the present owners Messrs. Royer and Elliott some time during the year 1903. This lease, as may be seen by the geological map, occupies the same zone as that which embraces the Klondyke Boulder mine, G.M.L. 604, from which it is distant 28 chains to the south-east. The surface of the property is occupied by the quartzitic rocks, and is traversed by the conspicuous vein of laminated quartz which forms the backbone of the district.

Judging by the condition of the surface a fair amount of work must have been done upon the lease; according to the official records 706·75 tons of ore have been raised, which yielded 4,700·76ozs. of gold, or at the rate of 6·65ozs. per ton of stone crushed.

When the property was visited the lease was not being worked, and owing to there apparently being no plans of the workings, very little information as to the nature and behaviour of the deposits is available. The Klondyke reef, as may be seen by the geological map, lies a little distance to the north of the leader.

The Main Reef enters the lease on its eastern boundary, where it has been open cut for about 27 feet; there is about a foot of quartz now showing. To a point about 117 feet east of this the reef has hardly been touched, it measures, however, four feet across; at this point is the mouth of a tunnel, put in along the reef for a distance of at least 300 feet. Seventy-two feet from the mouth of the tunnel is a winze, inaccessible at the present time, and said to be 90 feet; at this point there is 12 to 14 inches of quartz exposed over-head in the tunnel. The chute of gold followed from the mouth of the tunnel and by the winze is said to be 40 feet wide, with an underlay to the west. The reef has been practically stoped out to the surface to a point from the floor of the tunnel, about 129 feet from its mouth.

A vertical or main shaft connects with a point a few feet to the south of the drive, at a distance of 258 feet from the entrance to the tunnel. Judging from the condition of the workings, the tunnel did not follow the main reef, but merely a thin spur going off to the west.

Free gold is showing in the stone on the outcrop at a point about 50 feet west from the main shaft.

The following table shows the yield of the Klondyke Reef:—

Table showing the Yield of the Klondyke Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	63·00	836·00	13·27
1899	347·00	1,758·86	5·06
1900	144·50	1,566·20	10·83
1901	86·75	294·40	3·39
1902	65·50	245·30	3·74
1903	*Nil*	*Nil*	...
1904	25·00	83·64*	3·34
Total	**731·75**	**4,784·40**	**6·53**

* Includes 7·33ozs. obtained by cyaniding 9 tons of sands, the balance being returned from what is now known as the Klondyke Queen, G.M.L. 627.

KLONDYKE No. 1 EAST, G.M.L. 480.—This six-acre lease adjoins the Klondyke on the east, and is traversed by the leader, which crosses the whole length of the property.

A tunnel has been put in eastwards from the level of the creek, for an unknown distance, on a reef which bears 287 degrees

30 minutes. Further east along the outcrop is a vertical shaft 32 feet in depth, designed to connect with the tunnel below. The reef, as exposed on the surface, is about two feet in thickness. From its relative position there are good grounds for believing this reef to be the eastern extension of the Klondyke. There do not seem to have been any crushings from this property, unless such are included in returns from Sundry Claims.

BROUGHT TO LIGHT, G.M.L. 516.—This three-acre lease lies within that zone which includes the Bow Bells and Gauntlet Reefs. There are four well-defined reefs outcropping on the property, but upon one only has any work been done, viz., that near the noith-west angle of the adjoining lease number 515. This reef has been opened out along the outcrop for a distance of 50 feet, and in the open cut a vertical shaft 21 feet in depth has been sunk on the reef, which is about 12 inches in thickness. So far as can be seen the reef appears to have petered out at the foot of the shaft.

A small crushing of a little over eight tons has been recorded from this reef, and its yield is shown in the table below.

Table showing the Yield of the Brought to Light Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1899	8·75	7·96	·90

THE EARLY MORN, G.M.L. 515.—There are two or three well-defined reefs outcropping on this property, but upon none of them has any work been done.

KLONDYKE NO. 2 EAST, G.M.L. 481.—This lease adjoins the G.M.L. 478 on the north-west, and, like it, is traversed along its whole length by the leader. This, which occupies the southern portion of the property, has been opened out in one or two places.

A tunnel, the mouth of which is 35 feet north of the leader, and at a slightly higher level, has been put in, through vertical decomposed schists, for a distance of 84 feet, on a bearing of north 35 degrees east. With the exception of a few irregular quartz leaders, nothing of any importance seems to have been met with. A vertical shaft, designed to intersect this tunnel, was commenced, but after being carried down 10 feet work was abandoned. A second tunnel, 20 feet in length, has been put in at some distance from the longer one, but so far nothing is to be seen. There are two other reefs lying to the north of the leader, but nothing has been done upon them.

There seems to have been no crushings recorded from this lease, unless any such are included in the returns from Sundry Claims.

Admiral Dewey, G.M.L. 500.—This twelve-acre lease is situated due south of and adjoins G.M.L.s 478 and 481. There are several reefs traversing the property, the most conspicuous and persistent being that which outcrops along the southern boundary of the lease. The outcrop of the reef is interrupted in two places, as may be seen by an inspection of the plan. The country rock of these reefs is greenstone schist of the prevailing type. The only work carried out on this property is near the centre of the northern boundary, where a trench 16 feet long has been put in across the summit of a narrow ridge to a depth of four or five feet, in which an irregular network of quartz veins and leaders is exposed. The strike of the leaders is parallel to the enclosing schists.

There appears to have been only one crushing recorded from this lease, as shown in the return.

Table showing the Yield of the Admiral Dewey Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	8·45	4·55	·53

Klondyke King Blocks No. 1, G.M.L. 511.—This lease lies due north of and adjoins G.M.L. 578; it is traversed by two well-defined reefs, which lie within that zone, embracing the Gauntlet and the Bow Bells reefs.

No work of any kind, however, has been done upon these reefs.

Klondyke King, G.M.L. 478.—This six-acre lease adjoins the Klondyke Queen on the west, and, like it, is traversed by the leader, as well as two other reefs of minor importance on the north. The property, however, has long since been abandoned, though a fair quantity of work has apparently been done upon it.

A tunnel 44 feet in length has been put in on a bearing of 27 degrees through the schists to the leader, which has been connected with the surface by a shaft 31 feet deep. The workings from the tunnel are connected with another shaft 24 feet deep, and situated 48 feet to the west.

The leader, so far as it can be seen, does not present any essential points of difference to that in other portions of the field.

Klondyke Queen, G.M.L. 488.—The leader traverses the whole length of the lease on the southern flanks of the laminated quartz vein, but the former does not appear to have been opened out at all. The only work done upon the property is the sinking of a vertical shaft 32 feet deep on a very short east and west reef situated at a point 54 feet north of the laminated quartz vein. An open cut extends south from the vertical shaft and exposes decomposed country rock of the prevailing type.

The only crushing recorded from this lease must have been taken from the east and west reef, previously alluded to. The returns are shown in the table below:—

Table showing the Yield of the Klondyke Queen Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	**9·90**	**13·75**	**1·38**

Klondyke Queen Extended, G.M.L. 503.—A small three-acre lease, adjoining the Dead Camel, on the north-west. The property is traversed by the north-western extension of the leader, a fair amount of work having been done along its outcrop, but only to a very shallow depth. There appear to have been no crushings recorded from this property, unless such are included in the returns from Sundry Claims.

To the south of G.M.L. 503 is a faulted inlier of quartzite, in the form of a large attenuated lens, of considerable length but no great breadth. This, however, is too small to be shown on the geological map accompanying the report.

Dead Camel, G.M.L. 475.—The "leader" is continuous through this property, and has been worked for about 100 feet along the outcrop.

A vertical shaft 91 feet in depth has been sunk at one point on the outcrop. Below a depth of 84 feet nothing can be seen of the leader, owing to the shaft being filled in. At the foot of the shaft, so far as can be at present seen, the reef is of the usual lens-shaped type: the lenses being up to eight inches in thickness, and up to 18 inches in depth.

Free gold is showing in the stone, in addition to pyrites and galena [**5786**] and serpentine.

In addition to the leader there are two other quartz reefs on the property situated on the north side of the laminated quartz vein, but no work has been done upon them.

The returns from this reef are shown in the table below.

Table showing the Yield of the Dead Camel Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	2·50	9·10	3·64
1899	16·25	54·40	3·34
Total	**18·75**	**63·50**	**3·38**

Saint George No. 1 West, G.M.L. 498.—The reef outcropping in the Saint George traverses the eastern portion of this lease, but little is to be seen. Mr. Inspector Gladstone reports that "an open cut has been worked on the reef. Two shafts have been started and are down* about 10 feet. The reef here is two feet six inches thick."

Saint George, G.M.L. 493.—The 12-acre lease, the Saint George, lies some distance to the north of the leader, and has evidently been abandoned for some considerable time. There has evidently been a good deal of work done on the reef at one time or another. Little or nothing, however, can be seen at the present time. Mr. Inspector Gladstone's report, previously alluded to, makes reference to this property in the following terms:—"This is one of the best of the eastern leases on the line. One shaft is down 45 feet, with an open cut about 20 feet. The reef varies from 10 to 15 inches and is very rich in gold. The first crushing gave 110ozs. of gold from 11 tons of quartz." The quartz as showing in the face of the open cut near the shaft is pure white and about one foot in thickness.

The following table gives the yield of this reef:—

Table showing the Yield of the Saint George Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	20·00	124·00	6·20

Saint George No. 1 East, G.M.L. 499.—Very little work has been done on the reefs traversing this property. There are about three shallow pot-holes, from which about 3 tons of reputedly rich stone have been unearthed.

Last Chance, G.M.L. 540.—An abandoned lease. A fairly well-marked reef, from 12 to 18 inches in thickness, traverses the lease in a north-westerly and south-easterly direction, but beyond opening out the outcrop very little work appears to have been done upon it. The quartz is bluish-white, and contains a little pyrites.

Band of Hope, G.M.L. 533.—An abandoned six-acre lease adjoining G.M.L. 540 on the east. The main reef traversing the adjoining property crosses the northern portion of the Band of Hope; there are also two other veins to the south of it on the ground, trending approximately in the same direction, but no serious work of any kind has been done upon them.

* August, 1898.

Cuban, G.M.L. 492.—A similar condition of affairs prevails on this property as on the Britannia.

The leader, which traverses the whole length of the lease, has been worked to a shallow depth along practically the whole length of the outcrop. At the present time no work is going on, and there is little or nothing to be seen. Mr. Inspector Gladstone's report of 1898 mentions a vertical shaft 20 feet deep, and alludes to a trench 120 feet in length along the outcrop of the leader.

The following table shows the yield of the leader traversing the lease, as obtained from official sources.

Table showing the Yield of the Cuban Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	5·00	17·08	3·41
1899	18·20	74·33	4·08
1900	28·10	124·00	4·41
Totals	**51·30**	**215·41**	**4·19**

Britannia, G.M.L. 484.—An abandoned six-acre lease, adjoining the Reward and G.M.L. 522 on the west.

A good deal of work has been done along Kopcke's leader, but little can be seen at the present time. Mr. Inspector Gladstone, writing in 1898, metions a vertical shaft 27 feet in depth, and a trench 160 feet in length: none of these are accessible at the present time, hence no description can be given.

The following table gives the returns from this lease:—

Table showing the Yield of the Britannia Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	9·50	19·85	2·09
1899	9·50	8·85	·93
Total	**19·00**	**28·70**	**1·51**

Kopcke's Reward Block, G.M.L. 522.—There are four short though well-defined reefs outcropping on this lease, but no work of any kind has been done upon them.

Reward Claim 94.—A good deal of work seems to have been done upon this lease. The leader has been worked for a length of 320 feet along the outcrop. There are two vertical shafts 80 feet apart. The western shaft attains a vertical depth of 50 feet, and has been put down on the western end of a slope, along the footwall of the vein. At the foot of the shaft is a quartz lenticule about three inches in thickness; on the hanging wall side of the vein is about eight to twelve inches of laminated quartz, passing gradually into the softer decomposed (aluminous) country rock. The eastern shaft has been carried down to a vertical depth of 130 feet, but has been filled up to a depth of 100 feet. The largest of the quartz lenses exposed attains a maximum thickness of 12 inches, and a minimum of a quarter of an inch. The quartz contains a little pyrites, green carbonate of copper, and a little galena, which latter occurs pretty well all along the leader. Free gold is showing in the stone at grass, of which there was about 40 tons awaiting crushing. The charges for crushing (30s.) and cartage (10s.) amount to about £2 per ton.

The following table gives the yield of this lease :—

Table showing the Yield of Kopcke's Reward Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	31·00	160·59	5·18
1899	67·85	210·06	3·09
1900	36·25	101·75	2·80
1901	46·25	126·60	2·73
1902	49·70	147·26	2·96
1903	71·50	166·25	2·32
1904	49·00	125·38	2·55
Total	**351·55**	**1,037·89**	**2·95**

Whenna-pai, G.M.L. 532.—A small three-acre lease traversed by the leader, upon which a little work has been done, but the workings are inaccessible.

Daylight, G.M.L., 496.—An abandoned six-acre lease adjoining the Juneau on the west.

A good deal of work has been done at different points along the outcrop of the leader, which traverses the whole length of the property. A tunnel 45 feet in length has been put in eastward, close to the eastern boundary of the lease, and exposes quartz lenticules of the usual type. Mr. Inspector Gladstone, writing in

1898, noted the sinking of a vertical shaft 25 feet deep, but such was not accessible to me.

Juneau, G.M.L. 479.—An abandoned six-acre lease adjoining the Criterion on the west. The only work done is an open cut about 120 feet in length put down to a maximum depth of 15 feet upon the line of lenticular quartz veins, the leader. As exposed in the open cut the width of one of these quartz lenses in two inches, and its depth 12 inches. About 100 feet south of the leader is a large ice-like quartz reef parallel to it, and outcropping for about 100 feet along the surface.

Two small crushings have been recorded from this lease, particulars of which are given in the table below.

Table showing the Yield of the Juneau Reef

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	5·75	5·55	·96
1899	8·10	9·78	1·20
Total	**13·85**	**15·33**	**1·10**

Criterion, G.M.L. 508.—This property, now abandoned, lies at the south-eastern extremity of the long line of leases which extend across Warrawoona. A tunnel has been driven for a distance of 74 feet on a bearing of 208 degrees through decomposed schist inclined at a high angle to the north. At the face of the tunnel the main band of laminated quartz has been pierced. About a foot north from this is a quartz vein made up of small lenticules. Near the mouth of the tunnel is a vertical shaft measuring 29 feet in depth, but inaccessible at the present time. In addition to this and the tunnel, there are other workings, but as these are likewise inaccessible, no description can be given.

Near the south-eastern boundary of G.M.L. 508 (? on Lease 527, the Lucknow) is an open cut 60 feet in length, varying from 5 to 10 feet in depth, from which a vertical lenticular shaped quartz reef (or succession of quartz lenticules) has been extracted. This vein is the eastern extension of Kopcke's Leader. This open cut exposes a quartz reef underlying at 30 degrees in a direction of south 30 degrees east; there is a length of about 15 feet 4 inches exposed. At the surface the reef is 12 inches in thickness, and at

the bottom of the open cut, where it abuts against the leader, it has dwindled to four inches.

Table showing the Yield of the Criterion Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1898	8·00	3·30	·41
1899	4·20	4·50	1·07
Total	**12·20**	**7·80**	**·63**

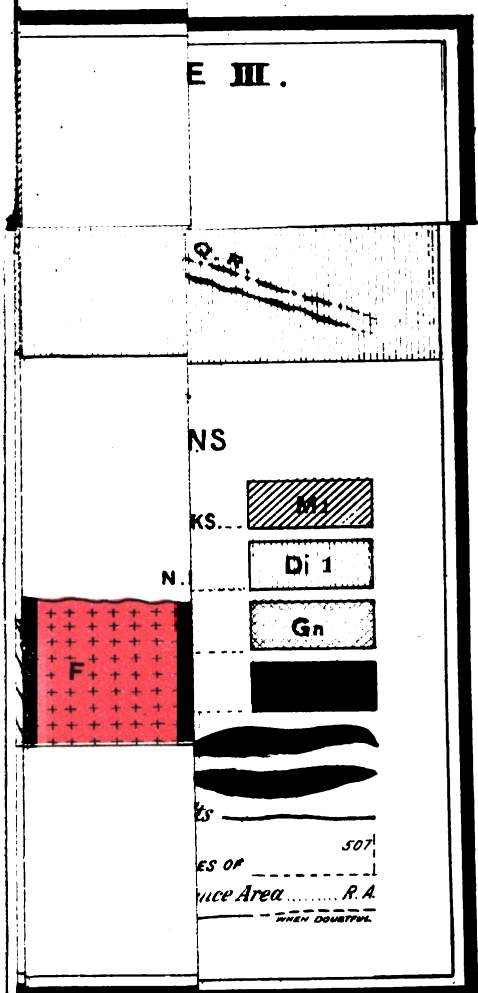
Lone Hand, G.M.L. 512.—The most easterly of all the leases embraced within the limits of the geological map. This property has been abandoned for some considerable time. Operations appear to have been confined to opening up a large and well-defined reef, which traverses the northern boundary of the property. The reef has been opened up in three places, along the outcrop, and where exposed, it varies in thickness from one to two feet. The quartz [**5783**] is white, and contains the following minerals, the numbers in parentheses indicating their relative frequency:—muscovite (3), limonite (3), malachite (2), pyrites (2), chalcopyrite (1), chalcedony (1), gold (1). In addition carbonate of iron is present in some parts. The reef which underlies to the south has a fairly long outcrop.

Sundry Claims from the District generally.—In addition to the yield of the reefs described above, there are several others which it is impossible to specify, and the returns from which are given in the table below:—

Table showing the Yield from Sundry Claims, Warrawoona.

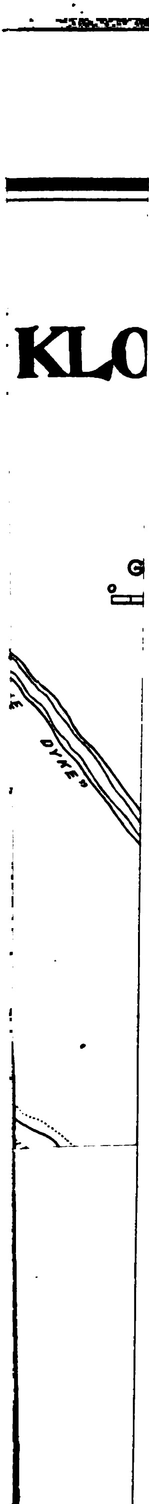
Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons	ozs.	ozs.
1897	5·00	28·93	5·78
1899	187·60	200·82 *50·00	1·07 ...
1900	12·20	32·50	2·66
1901	5·00	5·00	1·00
1902	22·50	35·02	1·55
1903	84·85	332·57 †433·30	3·91 ...
1904	70·45	‡138·45	1·96
Total	**387·60**	**§773·29**	**1·99**

* Alluvial. † Specimens. ‡ Fine gold. § Alluvial an specimens not included in total gold.



hotolithographer, Perth, W.A.

BULLETIN N°20 PLATE IV.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Synoptical Table showing the Yield of the Warrawoona Reefs up to the end of 1904.

Name of Reef.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
Admiral Dewey	8·45	4·55	·53
Bow Bells	483·70	855·69	1·76
Bow Bells Block No. 1 ...	12·00	10·50	·87
Britannia	19·00	28·70	1·51
Brought to Light ...	8·75	7·96	·90
Carnoustie	45·40	178·11	3·92
Chance	4·00	8·35	2·08
Criterion	12·20	7·80	·63
Cuban	51·30	215·41	4·19
Cutty Sark	36·05	59·10	1·64
Dead Camel	18·75	63·50	3·38
Gauntlet	1,289·30	3,693·55	2·86
Gift	44·05	73·50	1·66
Golden Gate	59·45	124·50	2·09
Golden Gauntlet	3·00	4·60	1·53
Imperialist	695·75	810·58	1·16
Juneau	13·85	15·33	1·10
Klondyke	731·75	4,784·40	6·53
Klondyke Block	37·00	764·00	20·65
Klondyke Boulder ...	1,016·16	2,450·93	2·41
Klondyke No. 1 West ...	43·00	189·67	4·41
Klondyke Queen	9·90	13·75	1·38
Nelson	1·25	5·29	4·23
Princept	2·15	5·00	2·32
Princess of Alaska ...	40·00	70·61	1·76
Rangatira	8·50	5·15	·60
Reward Claim 94	351·55	1,037·89	2·95
St. George	20·00	124·00	6·20
Tom Thumb	36·55	164·66	4·50
Treble Event	3·25	4·00	1·23
Wheel of Fortune ...	206·35	249·95	1·21
Sundry Claims	387·60	773·29 *50·00 †433·30	1·99
Cyaniding	...	‡6·56	...
Total	**5,700·01**	**17,294·18**	**3·03**

* Alluvial. † Specimens. ‡ Nine tons of sands.

C.—MARBLE BAR.

(*With a Geological Sketch Map and Section.*)

Marble Bar is the official centre of the Pilbara Goldfield, and the headquarters of the Warden, the Acting Inspector of Mines, and other officials. The relative position of the centre may be seen by a reference to the locality map which forms the frontispiece to this report. The locality derives its name from the picturesque "bar" of jasper which crosses the Coongan River, about two and a half miles to the south-west of the township. The district has had

a somewhat chequered career, and the feverish activity which at one time prevailed has given place to more prosaic conditions.

The mining centre of Marble Bar forms the westernmost extension of that auriferous zone referred to as the Marble Bar, Warrawoona, Yandicoogina, and Mount Elsie Group.*

A geological sketch map, to which is attached a generalised section across the field, designed to illustrate its salient structural features, accompanies this report (Plate VII.). As was the case in most of the other mining fields of the State, by far the larger portion of the area was practically a blank upon any of the existing maps, operations had to be commenced by preparing a plan of the more immediate vicinity of the mines.

Marble Bar lies close to what may be called the Main Range, which presents a fairly bold front to the eastward, and the country is drained by the Coongan River and its tributaries—Duffers and Sandy Creeks.

The Marble Bar centre presents features which link it geologically with Warrawoona and Yandicoogina.

Since the first discovery of the field, about 16 years ago, Marble Bar † has yielded 16,306·74ozs. of gold, resulting from the milling of 8,407·20 tons of ore; these figures give an average of 1·93ozs. of gold per ton. In addition to these figures there have been officially recorded 2,082ozs. from unknown tons, and 82ozs. of specimens, thus bringing the total yield up to 18,470·74ozs.

The various formations represented consist of a series of schists and allied rocks, granites, greenstones, and certain volcanic rocks, which may possibly represent the Nullagine Series as referred to in the earlier pages of the report.

The auriferous reefs of the more immediate vicinity of Marble Bar are embraced within a comparatively narrow belt of greenstone schist, running north and south, and which, as may be seen by an inspection of the Geological Sketch Map (Plate VII.), has a length of a little over three miles.

The district has been subjected to a considerable amount of faulting, and wherever possible the position and extent of these faults have been laid down upon the map.

General Geology.

The different rock masses have as far as possible been mapped, but it has not been found possible to do this in the same detailed way with regard to all the other rocks lying between Marble Bar and the Coongan River.

* Bulletin No. 15, p. 33 *et seq.*

† *i.e.*, the Marble Bar District as defined by the Mines Department.

Alluvial Deposits.

Most of the watercourses in the district are occupied with a more or less width of alluvium, but in no case did these deposits attain any great thickness, nor are they of any economical importance.

Schists.

By far the largest portion of the district embraced by the geological map is made up of schists, both acidic and basic, which bear a very strong resemblance to those occurring at Warrawoona.

Some of the schists in the vicinity of Hospital Hill, and adjoining the road to Nullagine near the crossing of Sandy Creek, are associated with beds which have every appearance of being transmuted quartzites and conglomerate. Much more detailed investigation, however, than was possible at the time I visited the district is necessary before it can be definitely asserted that these acidic schists are of sedimentary origin. So far, however, as can at present be seen, it appears that these schists are arranged in synclinal trough, as shown in the generalised section at the foot of the Geological Map.

These schists are of economic importance by reason of the fact that they almost invariably form the matrices of the auriferous quartz reefs.

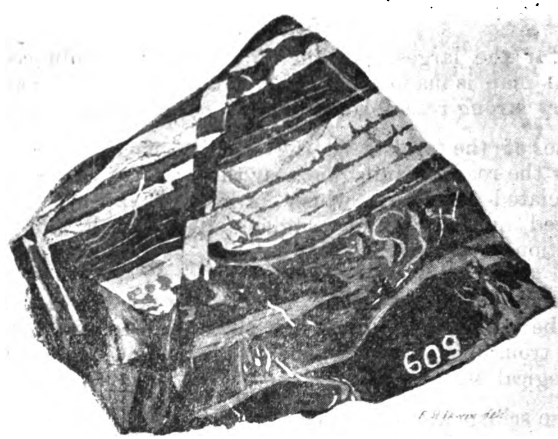
The schists are traversed by two bands of laminated quartz or jasper, the position of which is indicated on the geological map. The most conspicuous, however, is that known as the Marble Bar, which crosses the Coongan River about two and a-half miles south-west of the township. A view of this forms Photograph "I."

The "Bar" is a long razor-backed ridge (Photograph "J.") of laminated quartz or jasper, which rises to a considerable height above the general level of the surrounding country. The width of this band is naturally variable, but in one place near the Coongan River it measures as much as 220 feet from wall to wall. As seen in section, the banded jasper is inclined at an angle of 50 degrees to the north-west. The rocks forming this band can be followed across country for a considerable distance, and form a belt parallel to those similar beds described in Bulletin No. 15. The jaspers [**609, 3593, 3695**] present a brilliant appearance, due to the interlamination of red, white, and dark-coloured bands (Photograph "K.") with intermediate varieties, the differences in colour being due to the occurrence of iron in the form of either limonite, hematite, or magnetite. Some portions of the rock contain small but perfect crystals of magnetite.

When carefully examined the banded jasper is found to be much fractured and faulted, Fig. 12 [**609**], some of the cracks thus formed being filled with secondary silica. The occurrence of these cracks filled with secondary silica is such as to cause the stone to break up into slabs and blocks of an extremely irregular size.

The jasper takes an excellent polish and those portions of the rock which may be found free from flaws, etc., could doubtless be

FIG. 12.



Faulted Jasper, Marble Bar.

used for ornamental purposes were its geographical position somewhat more accessible. A typical sample [**3695**] of this banded jasper which was cut and polished in Europe for use at the Paris and Glasgow Exhibitions is now in the Museum of the Geological Survey.

Granite.

A very large area of country to the east of the township of Marble Bar is occupied by granite. The mass presents in places a very rugged surface, which rises in two conspicuous hills of considerable elevation about due east of the town. The granite presents the same general features throughout its whole extent. In its lithological characters it consists of quartz, felspar, and a little mica. The mass forms one extremity of that granite which embraces the Moolyella Tinfield described in Bulletin No. 15.

Porphyry.

The granite has been invaded by dykes of porphyry [**5392, 5812**], whilst a very extensive area occurs in the vicinity of Duffer's Creek. In their lithological character these porphyry dykes resemble those of Warrawoona very closely. An analysis of a typical porphyry [**5392**] is given on page 12 of Bulletin No. 15. These dykes agree very closely with those porphyries of Warrawoona, described in the earlier pages of this report.

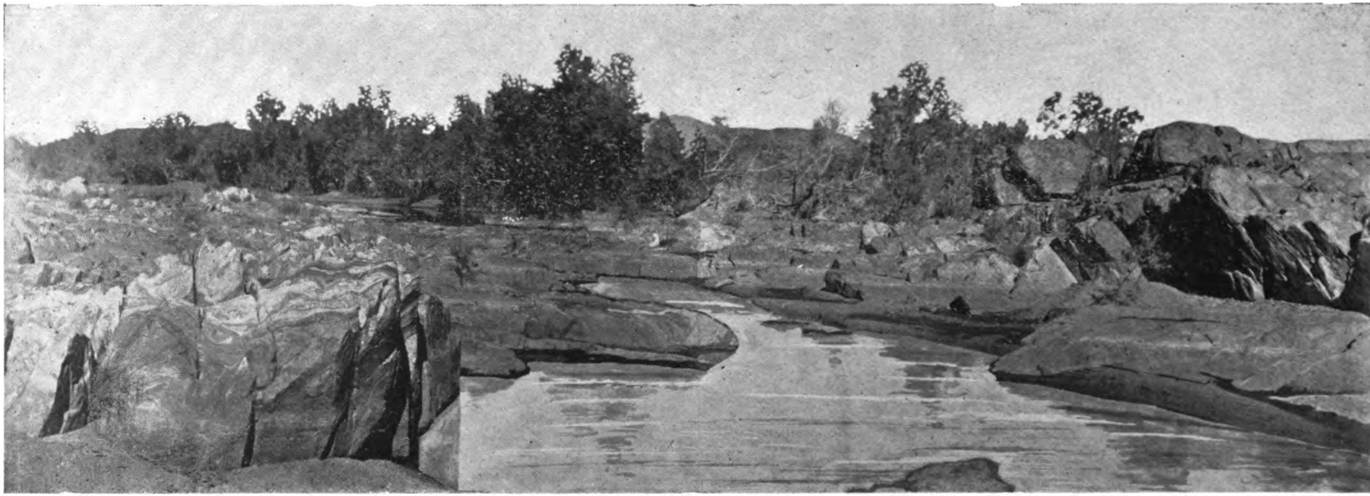


PHOTO.: S. J. BECHER

The Marble Bar, Coongan River.

J.

PHOTO.: S. J. BECHER.

Laminated Jaspideous Quartzite, Coongan River, near Marble Bar.

PHOTO.: S. J. BECHER.

Banded Jasper, near The Marble Bar, Coongan River.

Gabbro.

Adjoining that tributary of Duffer's Creek, close to the eastern boundary of the geological map, is a fairly extensive area of a dark green basic rock [**5809**] which consists of felspar (saussurite?), a ferro-magnesian constituent, which appears to be hypersthene and its alteration products, a little quartz, and an iron ore. Another similar area occurs a little to the south of the Ironclad Mine, G.M.L. 2.

Diabase Dykes.

A very important feature in the geology of Marble Bar is the number of basic dykes, which an examination of the geological map shows have a general easterly trend. The dykes are all readily distinguished by their dark greenish colour, a rusty and in places exfoliating weathering, and in the majority of cases a tending to verticality. The dykes have proved in the vicinity of Marble Bar of considerable value in working out the geological structure of the district. An inspection of the map demonstrates that only in one case do they intersect those sheared greenstones which form the auriferous series.

Owing to the marked features which many of these dykes exhibit on the surface, the mapping of them proved a relatively easy task. These basic rocks form part of that system of dykes which make such a marked feature in certain portions of the Pilbara Goldfield, and to which allusion has been made in the earlier pages of this report, and in Bulletin 15.

An examination of the geological map will show that many of these dykes have been faulted, but in no case does the horizontal shifting appear to have been very great. There are no data, however, by which any estimate of the amount of vertical displacement can be arrived at. The hade of the majority of the faults, however, is to the west, as may be seen in one or two sections. The dykes are all of a fine grain.

Economic Geology.

The Mines.

Although practically none of the mines at Marble Bar were open to my inspection, the following information extracted from the field notebooks of the late Mr. S. J. Becher give some idea of the condition of affairs prevailing, and other cognate points at the time this officer visited these properties.

In order to facilitate description the mines are described in geographical order, commencing at the northern end of the leases. The position of the various properties is shown upon the geological sketch map attached (Plate VII.).

Western Shaw No. 1 North, G.M.L. 291.—The most northerly of all the leases embraced within the area of the map, and traversed by four small quartz reefs, which underlie west. No work, however, appears to have been done upon them. The reefs

are enclosed in the belt of sheared greenstone, which forms the main auriferous series of the district.

IRONCLAD NORTH, G.M.L. 299.—The lease is traversed by a well-defined quartz reef, which extends along the whole length of the eastern boundary of the property, and underlies to the west.

The developments on the property consisted of two vertical and one underlay shaft. One shaft had been carried down to a vertical depth of 25 feet, and continued for a short distance on the reef. A drive had been put in to the north from the foot of the vertical shaft to a point 35 feet distant, where the reef pinched out. Another drive had been continued to the south for 74 feet, and the reef is said to have averaged three feet in thickness, but only crushed, however, 8dwts. to the ton.

The second vertical shaft was 55 feet in depth, but no particulars appear to be obtainable regarding it. The underlay shaft had been carried down 35 feet.

The yield of this reef may have been included under the heading of "Sundry Claims."

IRONCLAD, G.M.L. 2.—The ore deposits on the Ironclad Lease consist of five well-defined reefs, which lie within the belt of greenstone, as shown on the map. The surface of the western half of the lease is occupied by granite, beneath which the sheared greenstone passes. At one time a fifteen-head battery was erected on the property. Near the north-west angle of the lease is the well, near the old battery site, which had been carried down to a vertical depth of 92 feet. In this well the granite extends to a depth of 40 feet, at which point it gives place to schist. The water level is said to have been at 75 feet, and the amount of water which the well made was estimated at 600 gallons per hour.

The northernmost shaft on the field is an underlay put down on the reef at a point about five chains from the northern boundary, but this is at the present time totally inaccessible.

The principal work on the lease has been carried out upon what may be called the main Ironclad reef, which outcrops boldly along a low ridge near the eastern boundary of the lease.

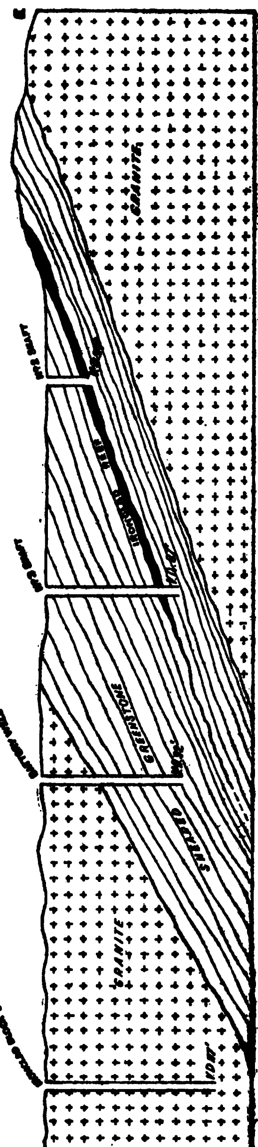
The stone which forms the main reef consists of white quartz, with very ferruginous patches.

A tunnel has been driven in from the side of the hill, along the strike of the reef on a bearing of 141 degrees for a distance of 145 feet, thence 14 feet on a bearing of 182 degrees to a point at which the main reef is first intersected. From this point a drive has been carried along the reef for a distance of at least 138 feet. The reef, as exposed at the first bend in the tunnel, measures three feet in thickness. These workings connect with the surface by two vertical shafts, one being 24 feet deep, and the reef stoped right up to the surface. In this portion of the workings the average thickness of the reef is four feet. The second vertical shaft, 128 feet west, had been carried down to a depth of 87 feet, and intersected the main

reef at 74 feet. A drive is said to have been put in 16 feet south on the reef, which has an average thickness of about 20 inches.

Fig. 13 shows a section across the Ironclad Reef, etc.

Fig. 13.



SECTION ACROSS THE IRONCLAD REEF MARBLE BAR.

Near the south-east angle of the lease are three inaccessible shafts, not indicated on the map; the northernmost of the group being an underlay put down on the reef to a depth of 120 feet. The reef is said to have attained an average thickness of five feet. A second underlay, some little distance to the south on the same reef, is said to have been carried down to a depth of 40 feet. West of this is a vertical shaft 34 feet deep.

The following table gives, so far as can be ascertained from official sources, the yield of the Ironclad Reef :—

Table showing the Yield of the Ironclad Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1893	297·00	774·30*	2·60
1894	94·00	163·00	1·73
1895	1,097·00	258·00	·23
1896	531·00	239·02	·45
1898	21·50	7·25	·34
Total	**2,040·50**	**1,441·57**	**·70**

* Of this amount, 418ozs. has been obtained from a crushing of unknown tons.

Ironclad South, G.M.L. 108.—This is a 24-acre lease, adjoining the Ironclad. There are three small but distinct reefs upon the property, but very little work of any description appears to have been done upon them. An opencut has been put in along the reef, averaging about 12 inches in thickness, which may represent the southern extension of the Ironclad. Three underlay shafts, 34, 54, and 20 feet respectively, have been put down, but these are inaccessible. The principal workings are an underlay shaft, 65 feet in depth, from which drives have been put in east and west for distances stated to be 60 and 20 feet respectively. The only separate record of any crushing from this mine is one in 1895 of 61 tons, which yielded 24ozs. of gold, or at the rate of ·39ozs. per ton.

Ironclad Block, G.M.L. 113.—The surface of the Ironclad Block Lease is occupied by granite, and a vertical shaft has been put down at a point seven chains from the south-east angle of the lease, and designed to intersect the main Ironclad Reef at about 200 feet. This shaft had been carried down to a vertical depth of 117 feet through granite. The relative position of this shaft is shown in Fig. 13, *supra*.

Iron Duke, G.M.L. 387.—This lease embraces part of an area which included the old leases, G.M.Ls. 63 and 8.

A shaft, not shown on the plan, has been put down to a depth of 40 feet, upon an approximately north and south reef, which is

stated to have been of very variable thickness, but to have reached as much as three feet. The reef which underlays west is of white quartz.

In 1896, 40 tons of quartz raised are stated to have yielded 25·70ozs., or at the rate of ·64ozs. per ton.

KEEP-IT-DARK, G.M.L. 296.—This old lease embraces a portion of the abandoned M.L. 8, The General.

A considerable amount of desolutory surface work has been done.

Two vertical shafts, 20 feet in depth, had been sunk upon the eastern extremity of the east and west reef, adjoining the main fault which traverses the property, but these were long ago abandoned. Two other underlay shafts, one of them 12 feet deep, had also been put down, but these were also inaccessible. A crushing of 32·5 tons in 1896 yielded 73·65ozs. of gold, or at the rate of 2·26 ozs. per ton.

The general reef outcrops upon what was originally M.L. 8 (G.M.L. 485) now embraced by G.M.L. 296.

The general reef which outcrops just outside the northern boundary of G.M.L. 296 is a well-defined body of quartz, striking north and south and underlying at an angle of between 40 and 50 degrees to the east. This reef has been extensively worked by the previous holders of the lease. The reef has been followed down from the surface for a distance of over 180 feet. A vertical shaft (Fig. 14) about 50 feet in depth intersected the reef, which was followed down for a further distance of 150 feet. The reef was abruptly cut off by a fault underlying west, but the shaft was continued for a further distance of 30 feet through country rock. A good deal of work appears to have been done underground, but there was very little to be seen at the present time. The fault seen at the bottom of the shaft is also visible in the workings at the eastern end of No. 1 level; the fault also underlies to the west. There are several faults in the vicinity of the reef, some of which are shown on the geological map (Plate VII.) so far as the small scale will admit.

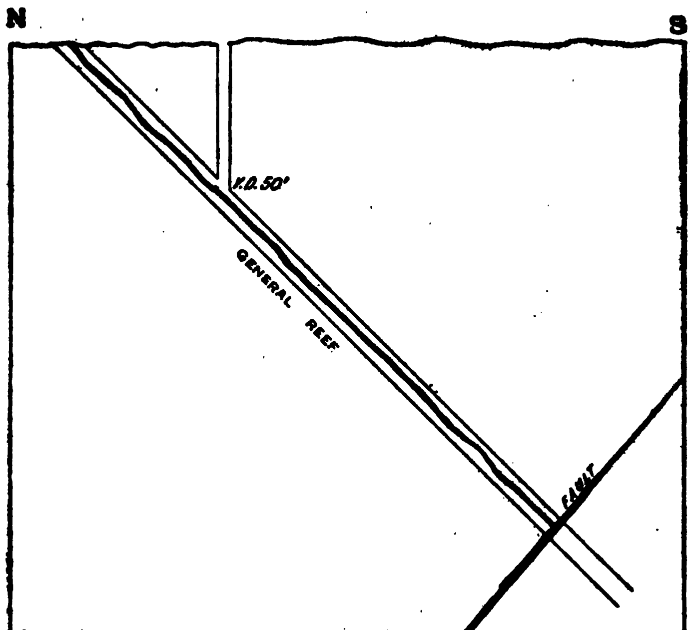
HOMEWARD BOUND, G.M.L. 613.—This lease embraces a portion of the ground embraced by the old Homeward Bound Lease, G.M.L. 579.

There is one fairly large-sized reef cropping out near the northern portion of the property, and trending generally north and south with an east and west arm. This reef is almost flat.

Upon the old Exhibition, G.M.L. 286, which includes the northern portion of the Homeward Bound, little else than surfacing seems to have been done.

Upon the greater portion of the western half of the Homeward Bound, lie all the old "Rejected" workings. Several shafts have been sunk, and much surface work done by previous owners upon an interrupted line of reef, which has a southerly underlay and a general east and west strike.

FIG. 14.



SECTION ACROSS THE GENERAL REEF MARBLE BAR.

The reef is said to lie fairly flat and with an average thickness of about 12 inches, with, however, big bunches here and there.

An underlay shaft had been sunk on the reef to a depth, on 17th September, 1896, of 50 feet on a good body of stone.

The Rejected No. 1 Reef (on old G.M.L. 84) does, however, appear to be upon exactly the same line as that just described. The reef outcropping has been worked by a main vertical shaft 40 feet in depth, which, up to the end of September, 1896, had been continued on the underlay for a further distance of 81 feet. Two reefs are said to have been exposed in the workings, separated by a horse of country. The lower reef is said to have possessed good, well-defined walls, which had an underlie of about 35 degrees to the south. The upper reef, reputed to have been the most regular of the two, had an average thickness of about two feet. Near the foot of the underlay shaft, the reef varied from 18 inches to five feet in width.

So far as can be ascertained from the official figures, the yield of the reefs on the present Homeward Bound Lease appears to have been as shown in the following table:—

Table showing the Yield of the Homeward Bound Reef.

Year.	Name of Lease.	Ore crushed.	Gold therefrom.	Rate per ton.	Total Ore crushed.	Total Gold therefrom.	Average rate per ton.
		tons.	ozs.	ozs.	tons.	ozs.	ozs.
Previous to 1897	Rejected, G.M.L. 105 ...	1,208·00	1,827·00	1·51			
1897 ...	Do. do. ...	65·00	67·00	1·03	1,273·00	1,894·00	1·48
1898 ...	Homeward Bound, G.M.L. 615	249·75	261·15	1·04			
1901 ...	Do. do. ...	198·75	242·25	1·22			
1902 ...	Do. do. ...	7·00	22·90	3·72	455·50	526·30	1·15
	Total				1,728·50	2,420·30	1·40

Shamrock, G.M.L. 160.—An old six-acre lease upon which a fair amount of work must have been done at one time or another. Near the north-eastern angle of the lease is an underlay shaft put down to a depth of 100 feet, on the reef outcropping on the crown of the hill. This reef was intersected by a vertical shaft, No. 1, and farther south-west by shaft No. 2, at depths of which there is no precise information. A third shaft had been sunk at a point 35 feet west of No. 1 to a depth of about 30 feet, but no particulars are available beyond the fact that a quartz reef five inches in thickness had been met with.

The following is a list of the crushings from this property, so far as are disclosed by the official statistics:—

Table showing the Yield of the Shamrock Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1895	52·25	120·10 *	2·29
1896	8·00	22·70	2·83
Total	**60·25**	**142·80**	**2·37**

* Includes 33ozs. from unknown tons.

True Blue, G.M.L. 157.—An old six-acre lease adjoining the Shamrock on the east. A considerable amount of open cast work has been carried out. The northernmost shaft on the lease is an underlay shaft 90 feet in depth, connecting with a vertical shaft 24 feet in depth, which had been continued for a further distance of 24 feet on the underlay of the reef. The reef averages two feet in thickness, and underlays about 30 degrees to the south-west. There

is another parallel reef below this one, which attains a thickness of about two feet.

The figures in the table below give the result of the crushings, so far as may be gathered from the official records :—

Table showing the Yield of the True Blue Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1893	*	61·20	...
1894	35·50	42·00	1·18
1895	92·50	168·82	1·82
1896	55·25	38·00	·68
Total	**183·25**	**310·02**	**1·69**

* Unknown.

Marble Bar, G.M.L. 288.—An old twelve-acre lease adjoining the Coongan Star Extended on the north, from which in the year 1898, 11 tons of ore yielded 15·70ozs. of gold, thus giving an average of 1·42ozs. of gold per ton.

Coongan Star, G.M.L. 92.—Upon this six-acre lease a good deal of *bonâ fide* work has apparently been done in times past upon a north and south reef, inclined at a very low angle to the west, but which makes no very pronounced outcrop on the surface. An old disused main shaft has been put down upon the summit of a low hill, and the reef worked out about 50 or 60 feet on the underlay.

A vertical shaft had been put down to a depth of 20 feet at a point 150 feet from the summit of the hill, but no particulars are obtainable respecting it.

Adjoining this is another 25 feet in depth, from the bottom of which a drive had been put in 40 feet to the south-east, whilst a third shaft near by had been sunk to an unknown depth. In addition to these old workings is a vertical shaft 33 feet in depth, at which point the reef is met with; this has been followed on the underlay for a further distance of 37 feet. About 100 tons of quartz have been raised and awaited crushing.

Table showing the Yield of the Coongan Star Reef.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1894	184·50	310·15	1·68
1895	75·50	131·80	1·74
1896	71·25	157·00	2·20
Total	**331·25**	**598·95**	**1·80**

Coongan Star Extended, G.M.L. 287.—Near the south end of the lease, adjoining the south-east angle of the Coongan Star property, a shaft 25 feet deep had been put down upon a small but good quartz vein, from which a small trial crushing is asserted to have yielded an average of about 2ozs. per ton.

A quartz reef in granite country outcrops near the north-west angle of the lease, but no work appears to have been done upon it. A water shaft of unknown depth is to the west of the reef.

Augusta, G.M.L. 615.—This lease, as at present constituted, embraces by far the larger portion of what was originally included in the Stray Shot, G.M.L. 3, the Excelsior, G.M.L. 21, and the Augusta, G.M.L. 7.

The Augusta reef makes a fairly distinct and well marked outcrop on the surface; the reef, however, has been interrupted near the southern angle of G.M.L. 280, by a north and south fault, which has but a slight throw.

The outcrop of the reef is traceable all round the north-east, east, and south-east sides of the hill, and averages about three feet in width, it extends westwards as far as the Stray Shot, where it is worked by several shafts. There seems, however, good reason to believe that the reef in the Surprise Lease, G.M.L. 167, adjoining the Stray Shot on the west, is the continuation of the Augusta, interrupted, however, by a small fault, lying parallel to that alluded to above. Along the eastern outcrop of the main Augusta reef stone has been broken out in several places.

The Augusta Reef has been worked by a main shaft which has been carried down on the underlie of the reef which is very flat for a considerable distance.

At the 75 feet, 150 feet, and the 266 feet levels drives have been put in for varying distances, but in the absence of an adequate plan of the mine any intelligible description of the reef underground is well nigh impossible, more especially as the majority of the workings are inaccessible.

Overlying the reef is a dyke [5819] of a fine-grained rock, which, under the microscope, seems to consist principally of felspar and an altered dichroic ferro-magnesian constituent.

In the underlay shaft at the 75 feet level the main Augusta Reef is said to have attained a maximum thickness of seven feet, but in the lower levels of the mine it averages only about 12 inches. It is stated that where the reef is wide the good stone is confined to certain bands, chiefly, however, of highly-mineralised bands; in the lower levels of the mine, where the reef is smaller, most of the stone is said to have been worth crushing.

The main Augusta Reef extends right through the Excelsior and the Stray Shot, below the level of the Stray Shot Reef. A great number of shafts have been sunk at relatively short distances apart on the slope of the hill and a considerable amount of surface

work done. The quartz is of a darkish hue, and contains relatively small quantities of the sulphides of iron, copper, and lead.

Table showing the Yield of the Augusta, Stray Shot, and Excelsior Reefs.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
Previous to 1897	3,349·00	9,219·00 *2,082·00	2·75
1897	1,661·70	1,818·28	1·09
1898	291·70	363·49	1·24
1899	230·00	322·40	1·40
1900	72·00	30·96 †195·00	·43
1901	15·00	26·60	1·77
Total	**5,619·40**	**‡11,780·73**	**2·09**

* From unknown tons. † From tailings. ‡ Does not include ounces from unknown tons and from tailings.

Sundry Claims from the District generally.—In addition to the yield of the reefs described above, there are several others which it is impossible to specify and the returns from which are given in the table below :—

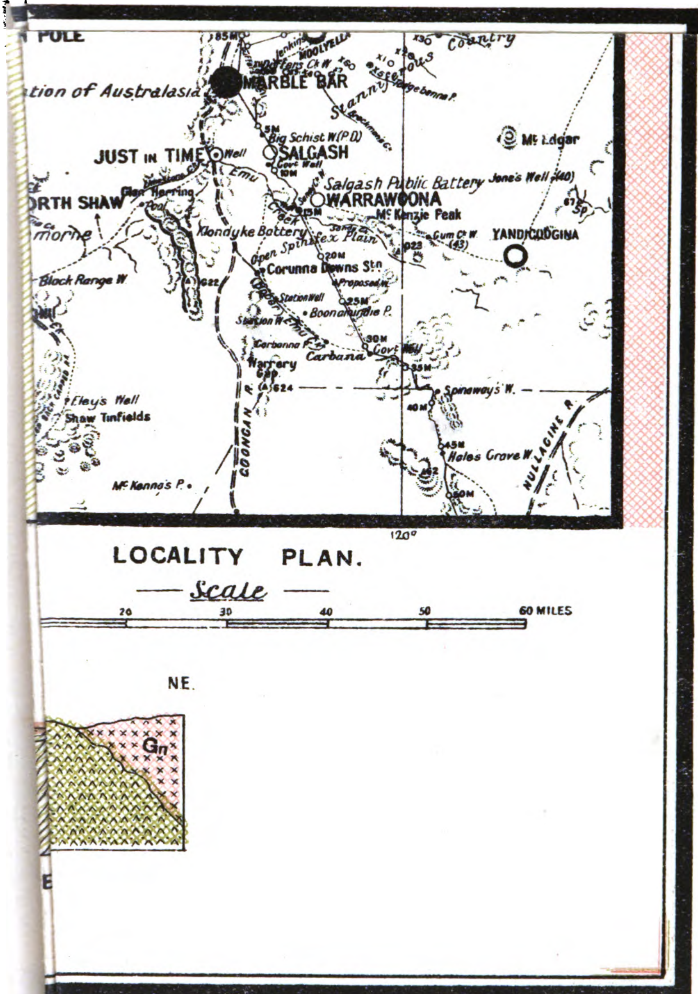
Table showing the Yield from Sundry Claims, Marble Bar.

Year.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
1897	94·50	119·17	1·26
1898	206·00	444·15 *1,000·00	2·15
1899	104·30	244·62 *1,770·00	2·34
1900	15·00	14·00	·93
1903	24·00	24·00	1·00
1904	...	†916·35	...
Total	**443·80**	**‡845·94**	**1·90**

* Alluvial. † Alluvial and dollied. ‡ Does not include alluvial and dollied.

It is, however, not quite clear from the manner in which the returns are presented whether or not these sundry claims include the yield from reefs in other centres not embraced within the limits of the Geological Map of Marble Bar.

PLATE VII.



H. J. Pether, Government Photolithographer, Perth, W.A.

Synoptical Table showing the Yield of the Marble Bar Reefs up to the end of 1904.

Name of Reef.	Ore crushed.	Gold therefrom.	Rate per ton.
	tons.	ozs.	ozs.
Augusta	5,619·40	14,057·73	2·50
Augusta No. 1 South ...	66·00	149·60	2·26
Coongan Star	331·25	598·95	1·80
Excelsior	Included under Augusta.		
General	Included under Homeward Bound.		
Homeward Bound ...	1,728·50	2,420·30	1·40
Ironclad	2,040·50	1,441·57	·70
Ironclad South	61·00	24·00	·39
Iron Duke	40·00	25·70	·64
Keep-it-Dark	32·50	73.65	2·26
Marble Bar	11·00	15·70	1·42
Pillendinnie	1·00	342·00	342·00
Rejected	Included under Homeward Bound.		
Robert Bruce	112·00	116·92	1·04
Shamrock	60·25	142·80	2·37
Stray Shot	Included under Augusta.		
Sundry Claims	443·80	4,532·29	10·21
Trafalgar	30·00	90·00	3·00
True Blue	183·25	310·02	1·69
Total	10,760·45	24,341·23	2·26

General.

In the latter end of last year, while in the North-West, a communication was received from Mr. J. Isdell, M.L.A., the Parliamentary representative of the district, containing a request that the tailings in the Marble Bar District be experimented upon by the Department, with the view of suggesting a method by which the large quantity of gold reported to have been lost in previous years could be recovered.

In accordance with instructions, attention was devoted to the question while at Marble Bar, and the heap of accumulated tailings at (*a.*) the Ironclad Mine, and (*b.*) on M.A. 1, were sampled by myself and Mr. Talbot, the Field Assistant.

These, on being received in Perth, were dealt with in the official laboratory, and reported on by Mr. E. S. Simpson, as follows:—

"The following are the results of extraction tests made on two samples of tailings collected by you at Marble Bar:—

"G.S.L. 687, Ironclad Mine.—These tailings consisted mainly of quartz sand, with a small percentage of clay and iron oxides, a very small amount of pyrites and a minute trace of copper. No antimony was present. The samples carried 28 per cent. of slimes. Percolation was easy and rapid. Cyanide consumed 0·63 lbs. per ton. Assay value of tailings, 4dwts. 15grs. per ton; of residues, 1dwt. 9grs. per ton. Extraction, 70·3 per cent. after three days leaching.

"There are no metallurgical difficulties whatever in the way of treating these tailings by the cyanide process. The question of their successful treatment resolves itself into one of economics solely, viz., whether or not 13s. 9d. (the value of the gold which it is possible to extract) will, under local conditions, do more than pay for the cost of extraction.

"G.S.L. 688, M.A. 1.—These tailings also consist mainly of quartz sand, with a small percentage of clay and iron oxides, a trace of pyrites, a slight trace of antimony, and copper carbonates equal to 0·15 per cent. of copper. The sample contained 28 per cent. of slimes. Percolation was very good. Cyanide consumed was very high, viz., 4·19lbs. per ton, probably owing to the copper present. Assay value of tailings, 3dwts. 6grs. per ton; of residues, 1dwt. 22grs. per ton. Extraction 41·0 per cent., after three days leaching.

"It would appear to be impossible to treat these tailings successfully. In the first place they are not rich in gold; in the second, the copper present causes the extraction to be very low, and the consumption of cyanide so high as to be prohibitive."

INDEX TO NAMES OF PLACES, MINES, REEFS, Etc.

By Authority: A. Curtis, Acting Government Printer, Perth.

Annual Reports—*continued.*

3. **Progress Report for the Year 1899, containing—**

Summary Report; The Staff; Field Work; Principal Results of the Year's Field Operations; Laboratory Work; Mineral Collection; Notes on the Greenbushes Tinfield; Boring for Water at Mulgarrie; Boring for Water at Hayes' New Find; The Geology of the Bardoc District; On the Development of Mining in the locality of Donnybrook; The Geology of the North Lead, Kanowna; The Kanowna Great Boulder G.M.L. 885x; Exhibitions; Mineral Waters; Composition of Native Gold; Greenbushes Tin Ore; Cobalt Ores; Menzies Goldfield; Kalgoorlie Goldfield; Coolgardie Goldfield. Price, 1s. **1900.**

4. **Progress Report for the Year 1900, containing—**

Administrative Report; The Staff; Field Work; Principal Results of the Year's Field Operations; Kalgoorlie Goldfield; Phillips River Goldfield; Gold Finds on the Preston and Ferguson Rivers; The Present Condition and Future Prospects of the Greenbushes Tinfield; Boring for Coal near Albany; North Lead, Kanowna; Bulong Deep Leads; Coolgardie Deep Leads; Alluvial Deposits, Donnybrook Goldfield; Subsidy to the Norseman Gold Mines, Ltd.; Gascoyne District; Extension of Artesian Water-carrying Strata from South Australia; Laboratory Work; Office Accommodation. Price, 1s. **1901.**

5. **Progress Report for the Year 1901, containing—**

Administrative Report; The Staff; Field Work; Laboratory Work; Mineral Collection; School of Mines; Principal Results of the Year's Field Operations; Kimberley; Uaroo Find; Ashburton River; Gascoyne; The Island, Lake Austin; Mount Ida; Yardarino Bore; The Dundas Goldfield; The Phillips River Goldfield; Norseman Gold Mines, Ltd.; Alluvial Deposits, Siberia. Price, 1s. **1902.**

6. **Progress Report for the Year 1902, containing—**

Administrative Report; The Staff; Field Work; Laboratory Work; Mineral Collection; Principal Results of the Year's Field Operations. *Mineral Resources*—Iron Ore Deposits of Western Australia; Diatomaceous Earth, Wanneroo; The Reputed Petroliferous Deposits of the Warren and the Donnelly Rivers; Cue; Lennonville, Boogardie, and Mount Magnet; Yalgoo; Paddington and Broad Arrow; Queen Margaret G.M. Co., Ltd., Bulong. *Water Supply*—Wyndham; Metropolitan and Suburban Water Supply; Winning Pool, Gascoyne River. *Boring*—Carnarvon; Fremantle, Hampton Road; Northampton. Price, 2s. 6d. **1903.**

7. **Progress Report for the Year 1903, containing—**

Administrative Report; the Staff; Field Work; Laboratory Work Geological and Mineral Collection; Palæontological Work; Publications; Geological Map of Western Australia; Principal Results of the Year's Field Operations. *Mineral Resources*—Pilbarra Goldfield; Murchison Goldfield; Iron Deposits of the Murchison; Leonora; Edjudina and Yundamindera; Mulline, Ularring, Mulwarrie and Davyhurst; Black Range; Arrino Copper Deposits; Irwin River Coalfield; Cue Boring; State Battery, 20-Mile Sandy; Nullagine; State Aid for Shaft-sinking at the Barton Mine, Nullagine. *Miscellaneous Mineral Notes.*—Platinum and Osmiridium; Monazite; Zircon and Cyanite; Gemstones; Gypsum; Diatomite; Kanowna Pug; Chalk; Telluride of Gold; Tourmaline in Gold. *Water Supply*—York Reservoir Site; Canning River Reservoir; Helena Valley; Artesian Water, Eucla Division; Pelican Hill Bore, Carnarvon. Price, 2s. 6d. **1904.**

Bulletins. Price, 1s. each—

- I. Bibliography of the Geology of Western Australia: by A. Gibb Maitland, Government Geologist. 1898.
- II. The State of Mining in the Kimberley District, and the probability of obtaining Artesian Water between the Pilbarra Goldfields and the Great Desert: by R. Neil Smith, M.A., F.G.S., Mining Engineer. (*Out of print.*) 1899.
- III. The Geology of the Coolgardie Goldfield: by Torrington Blatchford, B.A., F.G.S., Assistant Geologist. 1899.
- IV. The Mineral Wealth of Western Australia: by A. Gibb Maitland, Government Geologist. 1900.
- V. The Phillips River Mining District: by Torrington Blatchford, B.A., F.G.S., Assistant Geologist. 1900.
- VI. Notes from the Departmental Laboratory: by E. S. Simpson, B.E., F.C.S., Mineralogist and Assayer. 1902.
- VII. Notes on the Auriferous Reefs of Cue and Day Dawn: by W. D. Campbell, Assistant Geologist. With a map. 1903.
- VIII. Lennonville, Mount Magnet, and Boogardie, Murchison Goldfield: by C. G. Gibson, B.E., Assistant Geologist. With a map. 1903.
- IX. The Geological Features and Mineral Resources of Northampton: by A. Gibb Maitland, with Appendices by H. P. Woodward, John Provis, and E. S. Simpson. With a map. 1903.
- X. Palæontological Contributions to the Geology of Western Australia. I. Descriptions of Carboniferous Fossils from the Gascoyne District: by R. Etheridge, jun., Curator of the Australian Museum, Sydney. 1903.
- XI. Notes on the Country between Edjudina and Yundamindera, North Coolgardie Goldfield: by A. Gibb Maitland, Government Geologist. With two maps. 1903.
- XII. The Geological Features and Mineral Resources of Mulline, Ularring, Mulwarrie, and Davyhurst, North Coolgardie Goldfield: by C. G. Gibson, B.E., Assistant Geologist. With two maps. 1903.
- XIII. Geology and Auriferous Deposits of Leonora, Mount Margaret Goldfield: by C. F. V. Jackson, Assistant Geologist. With map and sheet of sections. 1904.
- XIV. The Geology and Mineral Resources of a part of the Murchison Goldfield: by C. G. Gibson., B.E., Assistant Geologist. With nine maps and eight figures. 1904.
- XV. Preliminary Report on the Geological Features and Mineral Resources of the Pilbara Goldfield: by A. Gibb Maitland, Government Geologist. With eight maps and 25 figures. 1904.
- XVI. The Mineral Production of Western Australia up to the end of 1903: by A. Gibb Maitland and C. F. V. Jackson. With a map. 1904.
- XVII. Geology and Auriferous Deposits of Southern Cross: by Chas. G. Gibson, B.E., Assistant Geologist. With a map. 1904.
- XVIII. The Geological Features and Auriferous Deposits of Mount Morgans, and Notes on the Geology and Ore Deposits of Mulgabbie: by C. F. V. Jackson, Assistant Geologist. With two maps and sheet of sections. 1905
- XIX. Minerals of Economic Value: by E. S. Simpson, B.E., F.C.S., Mineralogist and Assayer. 1905

In preparation:

- Palæontological Contributions to the Geology of Western Australia, II.: by R. Etheridge, jun., and Professor Howchin.
- The Kalgoorlie Goldfield: by A. Gibb Maitland, W. D. Campbell, and E. S. Simpson.
- Geological Observations in the lesser known portions of the Kimberley Division: by A. Gibb Maitland and C. G. Gibson. With a map.
- Progress Report for the Year 1904.
- Geological Features and Auriferous Deposits of Norseman: by W. D. Campbell, with geological maps, mining plans, and sections.
- General Index to Reports 1870–1903.

To be had on application at the Geological Survey Office, Perth, Western Australia.